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EXPERIMENTAL CLEAN COMBUSTOR PROGRAM

Phase II Final Report

by

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GENERAL ELECTRIC COMPANY

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16. Abstract

The primary objectives of this three-phase program are to develop technology for the design of advanced combustors with significantly lower pollutant emission levels than those of current combustors, and to demonstrate these pollutant emission reductions in CF6-50C engine tests. The purpose of the Phase II Program was to further develop the two most promising concepts identified in the Phase I Program, the Double Annular Combustor and the Radial/Axial Staged Combustor, and to design a combustor and breadboard fuel splitter control for CF6-50 engine demonstration testing in the Phase III Program. Noise Measurement and Alternate Fuels Addendums to the basic program were conducted to obtain additional experimental data.

Twenty-one full annular and fifty-two sector combustor configurations were evaluated. Both combustor types demonstrated the capability for significantly reducing pollutant emission levels. The most promising results were obtained with the Double Annular Combustor. Rig test results corrected to CF6-50C engine conditions produced EPA emission parameters for CO HC, and NO_x of 3.4, 0.4, and 4.5 respectively. These levels represent CO, HC, and NO_x reductions of 69, 90, and 42 percent respectively from current combustor emission levels. The combustor also met smoke emission level requirements and development engine performance and installation requirements.

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SUMMARY

The primary objectives of this three-phase program are to develop technology for the design of advanced combustors with significantly lower pollutant exhaust emission levels than those of current combustors, and to demonstrate the pollution reductions in tests of a CF6-50 engine in 1976. The purpose of this Phase II Program was to further develop the performance and emission characteristics of the two most promising concepts identified in the Phase I Program - the Double Annular Combustor and the Radial/Axial Staged Combustor - and to define and provide a combustor design for CF6-50 engine demonstration testing in the Phase III Program. The Phase II efforts were successfully completed with the development of a Double Annular Combustor design which produced substantial reductions of all gaseous pollutants, provided low smoke emissions and met development engine performance requirements.

The Phase II Program efforts involved experimental evaluations in full annular and sector combustor rigs and preparation of detailed aeromechanical combustor designs suitable for engine installation and demonstration testing. A total of 21 test configurations were evaluated in the full annular CF6-50 combustor rig utilized in the Phase I Program. Detailed emission level data and other performance characteristics were obtained in these evaluations. In addition, 52 test configurations were evaluated in newly-constructed sector combustor rigs. These latter tests were directed toward screening and developing design modifications to provide reduced emission levels and improved performance characteristics for incorporation into the full annular test configurations and the engine combustor designs.

Both Phase II combustors, the Double Annular Combustor and the Radial/Axial Staged Combustor, incorporate two-stage burning, wherein the pilot stage operates alone at low power conditions, and both the pilot and main stages operate together at high power conditions. Both combustors demonstrated the capability of significantly reducing exhaust pollutants. The best Phase II results were obtained with the Double Annular Combustor, which produced CO, HC and NO_x EPAP values extrapolated to CF6-50C engines conditions of 3.4, 0.4 and 4.5, respectively. These represent respective CO, HC and NO_x reductions of 69, 90 and 42 percent, compared to current CF6-50C engine values. The combustor also met development engine performance requirements.

Because of the lower CO and HC emission levels of the Double Annular Combustor at idle and at high power operating conditions, and the generally satisfactory performance obtained with this design concept during Phase II, it was selected for the demonstrator engine evaluations to be performed in Phase III. The reduced combustion efficiency levels of the Radial/Axial Staged Combustor at high power operating conditions which were required to obtain significant NO_x reductions, and the occurrence of flame flashback into its main stage premixing passage were primary factors in the selection of the Double Annular Combustor design concept.

Pilot stage design modifications, applicable to either combustor type were identified during Phase II which provided significant reductions in idle emission levels and which also resulted in meeting key engine performance requirements, at ignition, altitude relight and low power operating conditions. The use of pressure-atomizing fuel nozzles, swirl cup mixing barrels and small dilution air jets in the pilot stage provided idle HC emission levels well below the program goal and CO emission levels slightly below the program goal with the Double Annular Combustor. The incorporation of similar design features in the Radial/Axial Staged Combustor also produced HC levels well below the program goal, and CO levels approaching the program goal. Although the lowest idle CO emission index obtained with the Radial/Axial Staged Combustor was significantly lower than that obtained with the production CF6-50 combustor, it was still somewhat higher than the levels achieved with the Double Annular Combustor. These low idle emission levels were obtained with no sacrifice in sea level or altitude ignition performance.

Main stage modifications aimed at further reductions in NO_x emission levels at high engine power operating conditions met with limited success. With the Double Annular Combustor, significant main stage performance improvements were obtained, but the NO_x emission levels at takeoff remained about the same as those of the final Phase I Program configuration, which were about 45 percent lower than the levels of the production CF6-50 combustor. The resulting NO_x EPA parameter for the Double Annular Combustor was about 50 percent higher than the applicable 1979 EPA NO_x standard. This degree of NO_x reduction was obtained with no penalty in high power combustion efficiency. Takeoff NO_x emission levels below the program goal were obtained with the Radial/Axial Staged Combustor, but at the expense of combustion efficiency. A direct tradeoff between NO_x and efficiency was found to exist at high power operating conditions, as the fuel split between the pilot and main stages were varied. At a combustion efficiency level of 99.8%, which is approximately the takeoff level required if 1979 EPA standards for CO and HC are to be met, the NO_x levels of the Radial/Axial Staged Combustor were about equivalent to those of the Double Annular Combustor.

The determination of the best fuel flow split between stages at intermediate power operating conditions, from an emission and/or a performance standpoint, was an important part of the Phase II investigations. Specifically, the fuel flow split between combustor stages at the EPA-defined approach operating condition was found to have a large impact on the calculated CO and HC EPA parameters for both combustors. Because of the low combustor fuel-air ratio, inlet temperature and inlet pressure levels at approach, high CO and HC levels resulted when the fuel was supplied to both stages with either combustor type. By fueling only the pilot stage at idle and approach, and both stages at climbout and takeoff, CO and HC EPA parameters below the applicable 1979 standards were consistently obtained with the Double Annular Combustor, and levels approaching the standards were obtained with the Radial/Axial Staged Combustor. No configuration tested met either the CO or HC standard with both stages uniformly fueled at approach, but some Double Annular Combustor configurations met both standards with all of the pilot stage and a portion of the main stage nozzles fueled. Because of these

factors, NO_x emission index reductions at the approach mode could not be obtained.

Both stages of the Double Annular Combustor and the Radial/Axial Staged Combustor were fueled at simulated CTOL cruise operating conditions during the Phase II tests. Best results were achieved with the Double Annular Combustor. All configurations of this combustor produced NO_x levels lower than those of the production CF6-50 combustor, with very high combustion efficiencies. The lowest level obtained was an emission index of 6.6 with a combustion efficiency above 99.8%. This represents a 60% reduction from the production combustor.

In sector tests, pilot stage swirl cup designs for both combustors were developed which met the altitude relight requirements of the CF6-50 engine and operated carbon-free at all conditions. Acceptable average exit temperature profiles for both combustors were obtained during the Phase II annular tests. Some further adjustments to the peak temperature profile will be required to satisfy engine requirements in Phase III.

Based on the Phase II results, the Phase III Double Annular Combustor is expected to meet development engine performance requirements and meet 1979 EPA Class T2 standards for CO, HC and smoke emission levels. The design is also expected to provide significant reductions in NO_x emission levels relative to the production CF6-50 combustor, but is not expected to meet the presently defined NO_x standard for Class T2 engines.

INTRODUCTION

Various studies to define the extent of contributions of turbine engine-powered aircraft to world wide pollution have been conducted. In general, these studies have shown that the overall contributions of aircraft turbine engine emissions to the air pollution problems of metropolitan areas are quite small, as compared to those of other contributors (Reference 1). The foremost concern associated with these engine exhaust emissions appears to be their possible impacts on the immediate areas surrounding major metropolitan airports. Because of the operating characteristics of most current turbojet and turbofan engines, the highest levels of the various objectionable exhaust constituents are typically generated at engine operating modes that occur in and around airports. Further, because large numbers of daily aircraft operations can occur in and around a given airport, the cumulative exhaust emissions resulting from these localized aircraft operations tend to be concentrated to some extent in the airport vicinity.

For these reasons, the U.S. Environmental Protection Agency (EPA) concluded that standards to regulate and minimize the quantities of carbon monoxide (CO), unburned or partially oxidized hydrocarbons (HC), oxides of nitrogen (NO_x) and smoke emissions discharged by aircraft, when operating within or near airports are needed. Based on this finding, such standards were defined for several different categories and types of fixed-wing, commercial aircraft engines and were issued in July 1973. For the most part, these standards become effective in 1979 (Reference 2).

The introduction of aircraft engine emissions into the stratosphere is another area of concern. It is thought that the continuous introduction of some engine exhaust products into the stratosphere by large aircraft fleets might, after extended time periods, result in adverse environment impacts. The introduction of NO_x emissions into the stratosphere has, in particular, been identified as an area of concern. The possible impacts of the introduction of these and other engine exhaust products into the stratosphere have been conducted by the U.S. Department of Transportation (Reference 3). The preliminary findings of this extensive program indicate that very low NO_x emission levels at high altitude cruise operating conditions may become an important need in future transport aircraft engines (Reference 4).

To minimize these possible adverse environmental effects, significant development efforts to provide technology for the control and reduction of the levels of the pollutant exhaust emissions of aircraft turbine engines have already been conducted by both government and industry organizations and major additional development efforts are currently underway. Significant advances have already been made in the development of engines with greatly reduced smoke emission levels. As a result, advanced transport aircraft engines, such as the General Electric CF6 engines, with virtually invisible smoke emission levels, have been developed and placed into service. These engines are, thus, already in compliance with the smoke emission standards which have been issued by the EPA.

At the present time, therefore, the primary pollutant reduction technology needs of nonafterburning engines involve the reduction of CO and HC emission levels at idle operating conditions and the reduction of NO_x emission levels during takeoff, climbout and cruise operations. The attainment of reduced exhaust emission levels in future engines primarily involves providing improved and modified main combustors for use in these engines. Major combustor design technology advances are needed to obtain these significant reductions in gaseous pollutant emissions.

To provide these needed combustor design technology advances, the Experimental Clean Combustor Program (ECCP) was initiated by the U.S. National Aeronautics and Space Administration (NASA) in 1972 (Reference 5). The overall objective of this major program is to define, develop and demonstrate technology for the design of low pollutant emission combustors for use in advanced commercial aircraft engines with high cycle pressure ratios, in the range of 20 to 35. However, it is also intended that this technology be applicable to advanced military aircraft engines. Because the smoke emission levels of advanced commercial and military aircraft engines have already been reduced to low values, the primary ECCP program focus is on reducing the CO, HC and NO_x emission levels of these engines.

The NASA/General Electric Experimental Clean Combustor Program is one of two programs that comprise the overall program. The work effort was initiated in January 1973, and is being conducted in three phases. Phase II, initiated in August 1974 and completed in November 1975, is the subject of this report. The purpose of this phase was to further develop the performance and emission characteristics of the two most promising combustor designs identified in Phase I, and to define a low emissions combustion system design suitable for CF6-50 engine demonstration in Phase III.

This report describes the two low pollution combustor concepts investigated - the Double Annular Combustor and the Radial/Axial Staged Combustor - and the test results obtained. Full annular and partial sectors of each low emission combustor design, sized to fit within the CF6-50 engine aerodynamic flowpath are described, and detailed performance and pollution data are reported. Data were obtained at test conditions simulating all important CF6-50 operating modes from ignition to takeoff, including altitude windmilling and cruise conditions, at test pressures up to 9.5 atmospheres. Also described are the program objectives and schedule, the aerodynamic and mechanical design features of the Phase III engine demonstrator combustor design, and current and future program efforts.

Detailed test results obtained as part of two Phase II Program Addendums - the Noise Measurement Addendum and the Alternate Fuels Addendum - are presented in References 8 and 9.

CHAPTER I

DESCRIPTION OF EXPERIMENTAL CLEAN COMBUSTOR PROGRAM

OVERALL PROGRAM DESCRIPTION

The Experimental Clean Combustor Program is a multi-year effort which is being conducted by the NASA-Lewis Research Center. The primary program objectives are:

- To generate and demonstrate the technology required to develop advanced commercial CTOL aircraft engines with significantly lower pollutant exhaust emission levels than those of current technology engines.

- To demonstrate the low pollutant emission levels in tests of advanced commercial aircraft turbofan engines.

The intent of this major program is to reduce pollutant emission levels by the development of advanced combustor designs, rather than by the use of special engine operational techniques and/or water injection methods. The program is aimed at generating technology which is primarily applicable to advanced commercial CTOL aircraft engines with high cycle pressure ratios, in the range of 20 to 35. However, it is also intended that this technology be applicable to advanced military aircraft engines. Because the smoke emission levels of advanced commercial and military aircraft engines have already been reduced to low values, the primary focus of the program is on reducing the levels of the gaseous pollutant emissions.

The NASA/General Electric Experimental Clean Combustor Program is one of two programs that comprise the overall effort. It is being conducted by the General Electric Aircraft Engine Group under contract to the NASA-Lewis Research Center. The design and development efforts are directed toward providing advanced combustors for use in the General Electric CF6-50 engine. This engine is an advanced, high bypass turbofan engine in the 218 kN (50,000 lb) rated thrust class, and is in commercial service in the McDonnell Douglas DC-10 Series 30 aircraft and in the Airbus Industrie A300B aircraft. While the CF6-50 engine is the specific intended application of the advanced combustor technology development efforts of this program, this technology should also be applicable to all advanced engines in the large thrust size category.

PROGRAM PLAN

The Experimental Clean Combustor Program is being conducted in three sequential, individually funded phases:

Phase I: Combustor Screening

Phase II: Combustor Refinement and Optimization

Phase III: Combustor-Engine Testing

Phase I Program

The Phase I Program, which has been completed, was an 18-month effort specifically directed toward screening a variety of combustor design approaches. The objective was to identify and develop promising combustor design approaches for obtaining the pollutant exhaust emission level reductions. Phase I Program efforts involved the definition of four advanced combustor design approaches, the detailed aeromechanical design of CF6-50 engine-size versions of these approaches, the fabrication of full annular versions and pollution and performance evaluation tests. Configurations were evaluated in a test rig which exactly duplicates the aerodynamic flowpath and envelope dimensions of the combustor housing of the CF6-50 engine, at operating conditions identical to those of the CF6-50 engine except for pressure level, which was restricted to 9.5 atmospheres or less due to test facility limitations. In these tests detailed measurements of the emission and performance characteristics of each combustor configuration were obtained.

In conjunction with Phase I, additional efforts were also carried out in two program addendums; the Advanced Supersonic Transport (AST) Addendum and the Combustion Noise Measurement Addendum. The purpose of the AST Addendum was to develop combustor design technology for reducing the NO_x emission levels of AST engines at supersonic cruise operating conditions by applying and extending the results of the basic program investigations. The purpose of the Combustion Noise Measurement Addendum was to obtain experimental data on the acoustic characteristics of these advanced low emission combustors and, thereby, to enable comparisons of their noise characteristics with those of current technology combustors.

Detailed descriptions and results of the Phase I Program and AST Addendum are presented in Reference 6. Combustor Noise Measurement Addendum results are presented in Reference 7.

Phase II Program

The Phase II Program, which has also been completed, was a 15-month effort to further develop the most promising advanced combustor designs evolved in the Phase I Program. The Double Annular Combustor and the Radial/Axial Staged Combustor design approaches produced the most promising Phase I results and were selected for Phase II development. Phase II efforts included both full annular and sector combustor component tests, detailed aeromechanical design of versions of these combustors for possible use in Phase III CF6-50 engine tests, and the design of a breadboard engine fuel control system. The primary objective of these design and development efforts was

to provide advanced combustor designs which meet the performance and installation requirements of the CF6-50 engine and approach the objective low pollution emission level goals of the program.

In conjunction with the Phase II Program, additional efforts were also carried out in two program addendums; the Noise Measurement Addendum and the Alternate Fuels Addendum. The purpose of the Noise Measurement Addendum was to obtain additional experimental data on the acoustic characteristics of these low emissions combustors and make direct comparisons of their noise characteristics with those of the current production CF6-50 combustor. The purpose of the Alternate Fuels Addendum was to obtain experimental data on the effect of relaxed fuel specificatons, such as final boiling point and hydrogen content, on the pollutant emission levels and performance characteristics of these low emissions combustors and the current production CF6-50 combustor.

Detailed descriptions and results of the Phase II Program are presented in Chapter II through V of this report. Descriptions and results of the two addendums are presented in References 8 and 9.

Phase III Program

The Phase III Program, which is currently underway, is a 16-month effort and consists of detailed evaluations of the most promising Phase II Program combustor design in a demonstrator CF6-50 engine. The objective is to demonstrate significant pollutant reductions with an advanced combustor which meets the performance, operational and installation requirements of the engine. The Double Annular Combustor design has been selected for these evaluations. The combustor incorporates all of the aero-thermal design features that evolved in the Phase II Program together with advanced mechanical and installation features derived from other General Electric combustor programs. General Electric is furnishing the required combustor parts, engine components and fuel supply/control components from another program.

A large turbofan engine has never before been operated with a two-stage main combustion system. Therefore, the objectives of these engine evaluations are not only to obtain steady-state performance and pollutant emission data, but to also determine experimentally, the acceleration and deceleration characteristics of the engine.

PROGRAM SCHEDULE

The overall schedule plans of the NASA/General Electric Experimental Clean Combustor Program are presented in Figure 1. In this chart, the solid bars indicate completed efforts and the striped bar indicates efforts currently under contract.

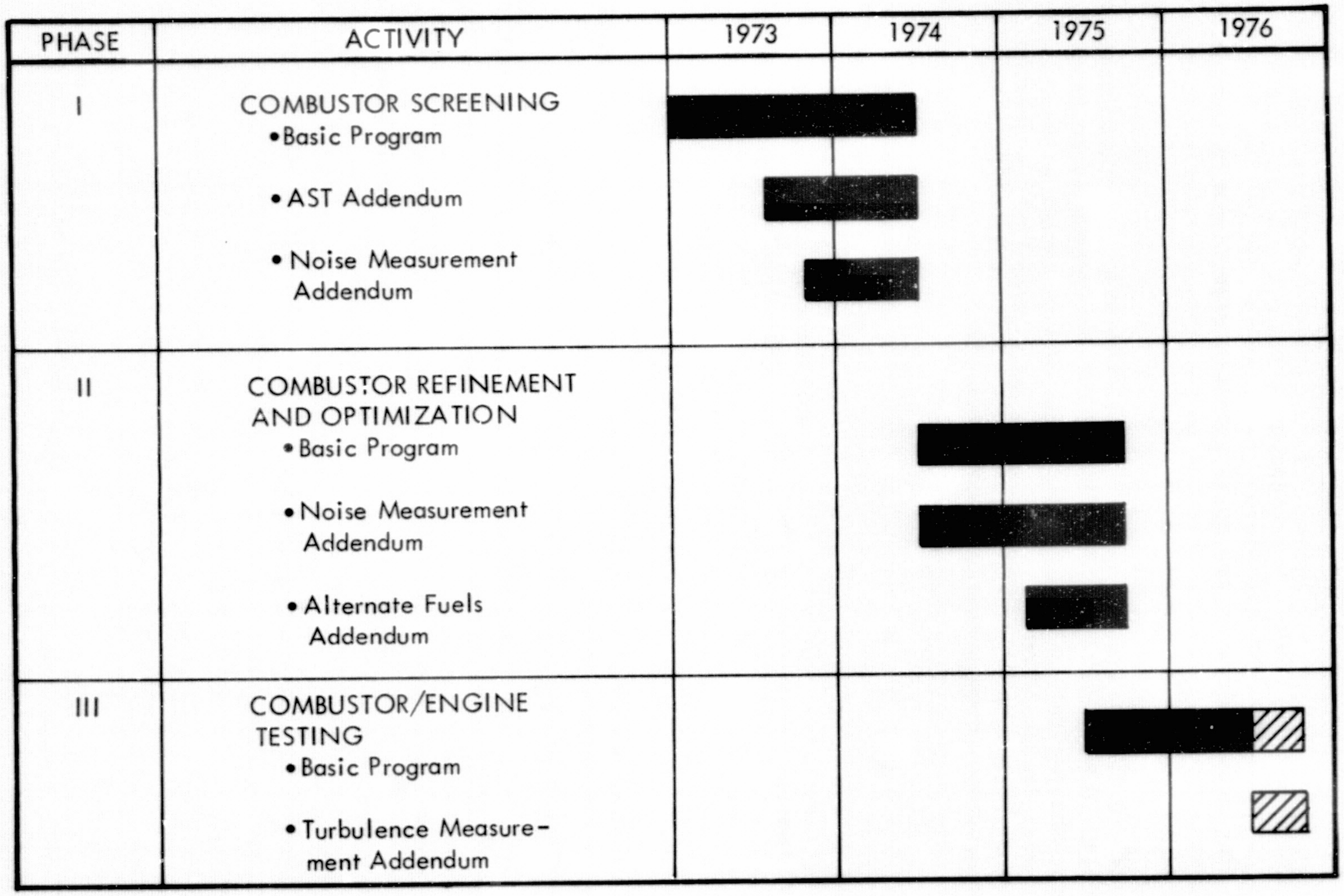


Figure 1. NASA/General Electric Experimental Clean Combustor Program Schedule.

PROGRAM GOALS

Pollutant Emission Level Goals

The pollutant emission goals are presented in Table I. As is shown by the comparison of the goals with the status levels of the current production CF6-50 engine, the attainment of these goals involves significant pollutant emission level reductions by factors of three to seven on an emission index basis.

These goals are intended to be optimistic projections of the attainable pollutant emission level reductions. The intent of the program is to generate advanced combustor design technology rather than to verify already available combustor design technology. Further, the use of water injection into the combustor to obtain lower NO_x emission levels, was specifically excluded as an approach to be considered in the program.

In Table I, the gaseous pollutant emission goals are expressed two ways; as emission indices at the engine operating mode where the peak levels of each emission are generated, and as EPA parameters by which the gaseous emission standards are defined in Reference 2. The EPA parameter is a thrust-normalized measure of the total mass of pollutant emitted in a prescribed takeoff and landing cycle. For the CF6-50 engine, the peak emission index goals are somewhat lower than needed to meet the EPA Standards.

Combustor Performance Goals

The key combustor performance goals are presented in Table II. Except for its combustion efficiency levels at low engine power operating modes, the current production CF6-50 engine combustor already provides performance levels equal to or better than the goals. Thus, the major challenge of this program is to develop advanced combustor designs which significantly reduce pollution levels without compromising performance characteristics. The current CF6-50 engine does not achieve the 99 percent combustion efficiency goal at the idle operating mode. This goal is specified as 99.0% to be consistent with the CO and HC emission level goals. Combined, these goals are equivalent to a combustion efficiency at idle of 99.1%.

Table I. Pollutant Emission Level Goals of the NASA/ General Electric Experimental Clean Combustor Phase II Program.

- Sea Level Static Engine Operating Conditions
- Standard Day Conditions
- Aviation Kerosene Fuel
- CF6-50C Power Rating

A. Peak Emission Goals

Pollutant Emission	Engine Operating Mode	Program Goal	Current CF6-50C Engine Status
NO_x (as NO_2) - g/kg fuel	Takeoff	10	35
CO - g/kg fuel	Ground Idle	20	73
HC (as $C_m H_{1.9m}$) - g/kg fuel	Ground Idle	4	30
Smoke - (SAE SN)	Takeoff	15	12

B. EPA Emission Parameter Goals

- Prescribed Class T2 Engine Takeoff/Landing Cycle

Pollutant Emission		Program* Goal	Current CF6-50C Engine Status
NO_x (as NO_2)	lb/1000 lb Thrust-hr	3.0	7.7
CO	lb/1000 lb Thrust-hr	4.3	10.8
HC	lb/1000 lb Thrust-hr	0.8	4.3

*Same as EPA 1979 Class T2 engine standards.

Table II. Combustor Performance Goals of the NASA/General Electric Experimental Clean Combustor Program.

Performance Parameter	Engine Operating Mode	Program Goal
Minimum Combustor Efficiency - %	All	99.0
Maximum Pressure Drop - %	Cruise	6.0
Maximum Exit Temperature Pattern Factor	Takeoff and Cruise	0.25
Altitude Relight	Windmilling	Meet CF6-50 Engine Relight Envelope
Mechanical Durability	All	Equivalent to Current CF6-50 Combustor

CHAPTER II

PHASE II PROGRAM DESIGN AND DEVELOPMENT APPROACHES

CF6-50 ENGINE/COMBUSTOR

The CF6-50 engine is the higher power series of two CF6 high bypass turbofan engines which have been developed by General Electric. The other series is the CF6-6 engine. The CF6-50 engine is in commercial service as the power plant for the McDonnell Douglas DC-10 Series 30 Tri-Jet long range intercontinental aircraft and the Airbus Industrie A300B aircraft. The CF6-50 engine is a dual-rotor, high bypass ratio turbofan incorporating variable stators, high pressure ratio compressor, an annular combustor, an air-cooled core engine turbine and a coaxial front fan with a low pressure turbine. Major features of the engine are shown in Figure 2.

Several models of the CF6-50 engine are currently in production. The CF6-50C model was selected for the Phase II Program combustor design and test conditions. Key standard day combustor operating conditions for this model are presented in Table III. The idle operating conditions are averages from acceptance tests of 109 production engines and are more severe, from an emissions standpoint, than were early cycle data used in the Phase I Program. The high power operating conditions in Table III are averages from acceptance tests of 17 production engines and are essentially the same as the early cycle data.

The CF6-50 engine combustor is a high performance design with demonstrated low exit temperature pattern factors, low pressure loss, high combustion efficiency and low smoke emission performance at all operating conditions. A cross sectional drawing of this combustor, as installed in the engines, is presented in Figure 3. Its key features are a low pressure loss step diffuser, a carbureting swirl cup dome design and a short burning length. Additional details of the CF6-50 engine and combustor are contained in Reference 6.

TEST FACILITIES AND EQUIPMENT

The Phase I Program evaluations were conducted with an existing full annular combustor test rig. The Phase II Program evaluations included both full annular and sector combustor rig tests. A new 60° sector combustor rig was utilized primarily for altitude relight and cross-firing development. A new 12° sector combustor rig was utilized for high pressure carboning and flashback development. Testing was conducted concurrently in all three rigs. Combustor modifications determined from sector rig tests were incorporated into the full annular combustor rig configurations where the bulk of the emission and performance development tests were conducted. All tests were conducted in facilities at the General Electric Evendale Plant.

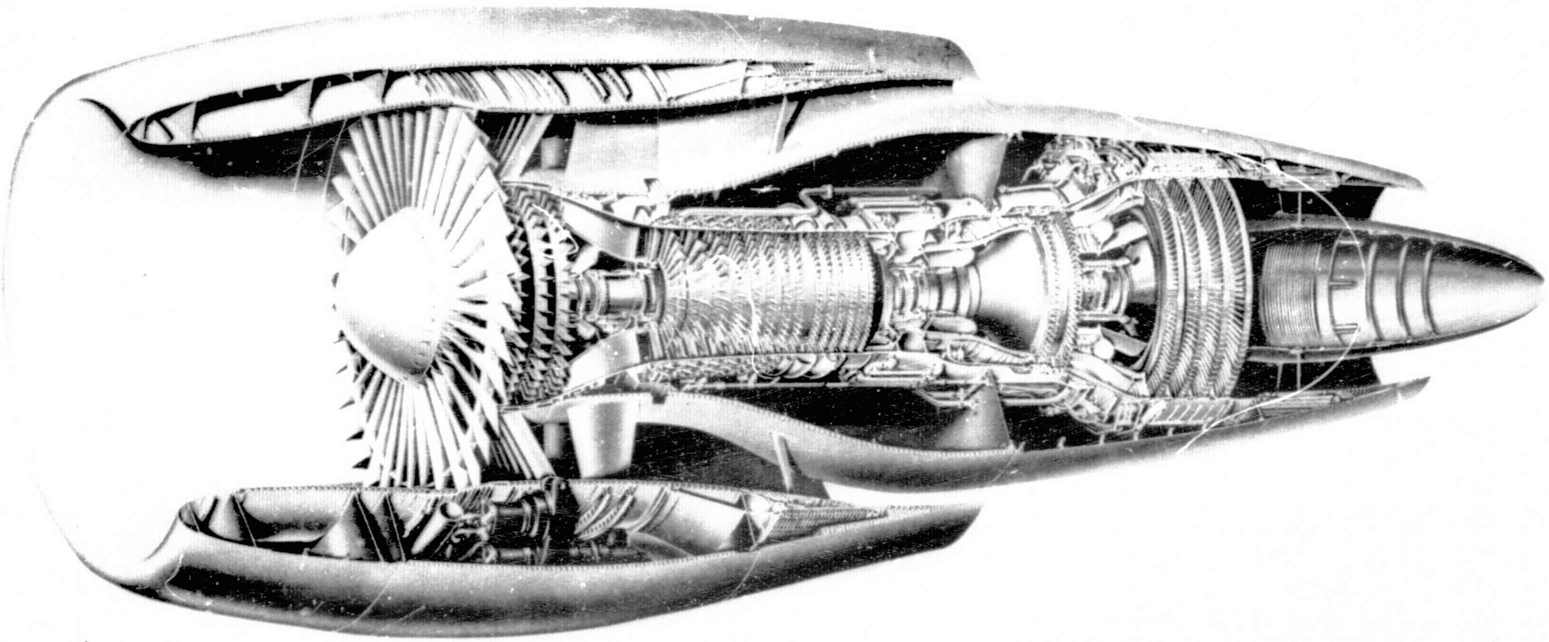


Figure 2. General Electric CF6-50 High Bypass Turbofan Engine.

Table III. CF6-50 Engine/Combustor Operating Conditions.

- Standard Day Conditions
- No Bleed Air Extraction
- Jet A Fuel

Parameter	Symbol	Units	Idle[1]	Approach[1]	Cruise[2]	Climb[1]	Takeoff[1]
Installed net thrust	F_N	kN	7.53	66.59	47.23	188.66	221.95
Percent takeoff thrust	PCFN	%	3.39	30.0	-	85.0	100.0
High pressure compressor physical speed	N_g	rpm	6412	8620	9585	9890	10150
High pressure compressor discharge total pressure	P_3	atm	2.92	11.7	11.4	25.9	29.8
High pressure compressor discharge total temperature	T_3	K	429	630	733	786	820
High pressure compressor discharge air flow	W_3	kg/s	16.37	56.7	49.5	109.3	122.0
Combustor air flow	W_{36}	kg/s	13.81	47.6	41.8	92.1	103.0
Ideal fuel flow[3]	$W_{F_{ideal}}$	kg/hr	547	2395	3159	7104	8573
Combustor reference velocity	V_R	m/s	18.3	23.2	24.3	25.3	25.6
Combustor fuel-air ratio[3]	f_{ideal}	-	0.0110	0.0140	0.0210	0.0214	0.0231

(1) Sea level static

(2) Altitude = 10.67 km, Flight Mach Number = 0.85

(3) Assumes combustion efficiency = 100%

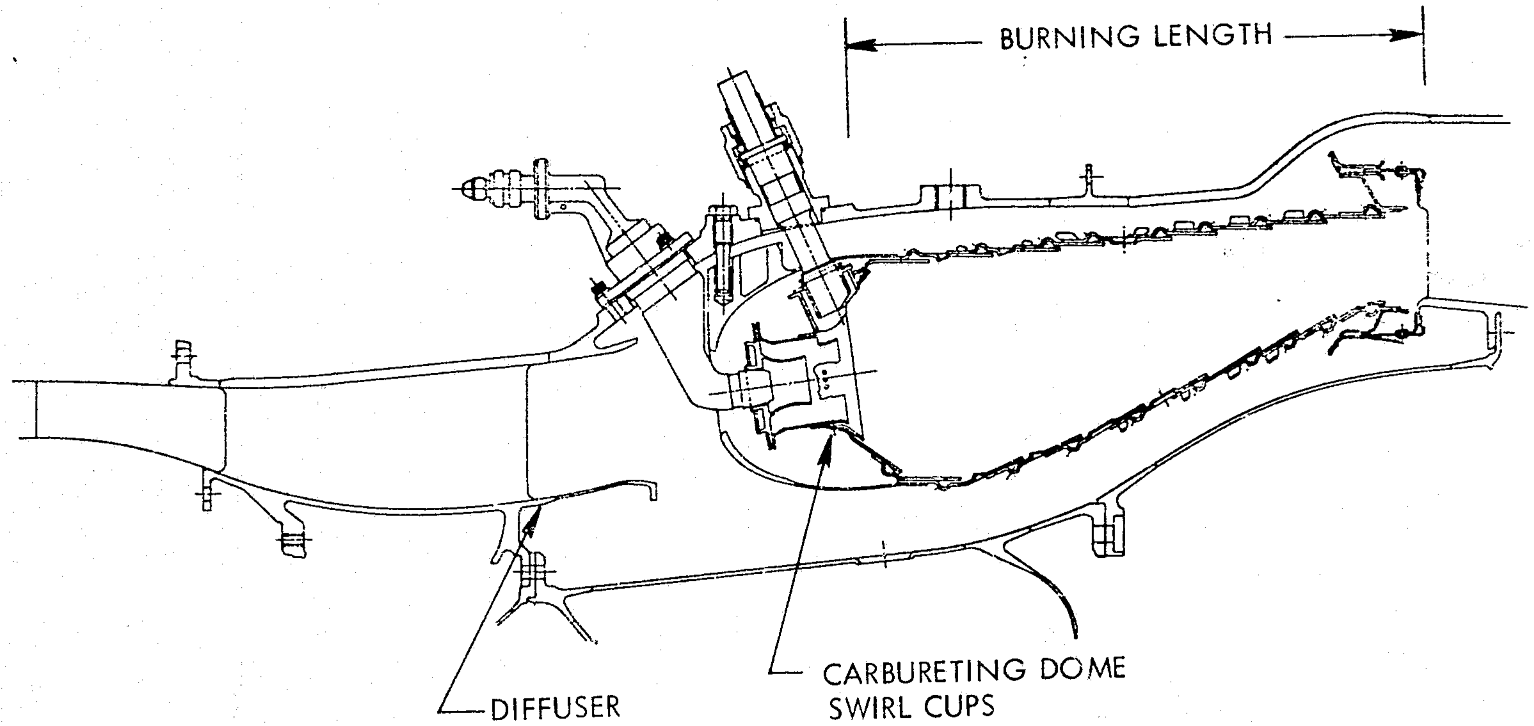


Figure 3. Production CF6-50 Engine Combustor.

Full Annular Combustor Rig

Full annular combustor tests were conducted with the same facility, rig and data acquisition systems utilized in the Phase I Program. Detailed descriptions are presented in Reference 6 and are briefly reviewed in this section.

Tests were conducted in Test Cell A3 which is equipped with an indirect gas-fired air heater and exhaust ducting systems for high pressure or vacuum operation. Flow capabilities are such that the CF6-50 engine combustor operating conditions can be exactly duplicated at all altitude relight requirement conditions and at ground idle conditions. For higher power simulation, combustor inlet pressure is limited to about 9.5 atm.

The test rig exactly duplicates the aerodynamic flow path and envelope dimensions of the CF6-50 engine. Included as a part of this rig is an exit plane rotating rake assembly for obtaining measurements of outlet temperatures and pressures and for extracting gas samples. A drawing of the rig is presented in Figure 4. Most of the tests were conducted with the rig connected to the facility exhaust system for pressure control. For ground starting and detailed pattern factor testing, the combustor was exhausted directly to the atmosphere. This atmospheric exhaust setup allows visual determinations of lightoff, propagation, blowout and provides a more detailed assessment of the exit temperature distribution.

The exhaust gas sampling rake traversing assembly contains five gas sample rakes each having five sampling probes. The probe tips are designed to quench the chemical reactions of the extracted gas sample as soon as the sample enters the rake. The rakes are water cooled for mechanical integrity, and sample lines within the rakes are steam heated to prevent condensation of hydrocarbon compounds and water vapor in the sample. The 25 individual sample lines are led out through steam heated bundles to a bank of selector valves in the control room, and then to the emission analyzers. A flow diagram of the sample lines is shown in Figure 5. By manipulation of the appropriate valves, any individual element or any desired combination of elements can be selected for measurement. Normally, 15 elements were manifolded together for gaseous analysis and ten elements were manifolded together for smoke measurements. The CO_2, CO, HC, and NO_x analyzers are electronically integrated with the test cell digital data acquisition system which allows gaseous emission data to be automatically recorded and reduced in the test cell in a matter of minutes. The smoke emission data are obtained using the standard General Electric filter stain method.

60° Sector Combustor Rig

A cross sectional drawing and an overall photograph of the 60° rig are shown in Figure 6. The combustor housing is constructed from a segment of a CF6-50 engine compressor rear frame and seal bearing assembly so it exactly duplicates the engine combustor flow path and ports. Radial sidewalls are uncooled, and air seals are provided to minimize end-wall effects. The exit instrumentation section has nine ports for mounting thermocouples or gas sample rakes in-line with and between fuel nozzles.

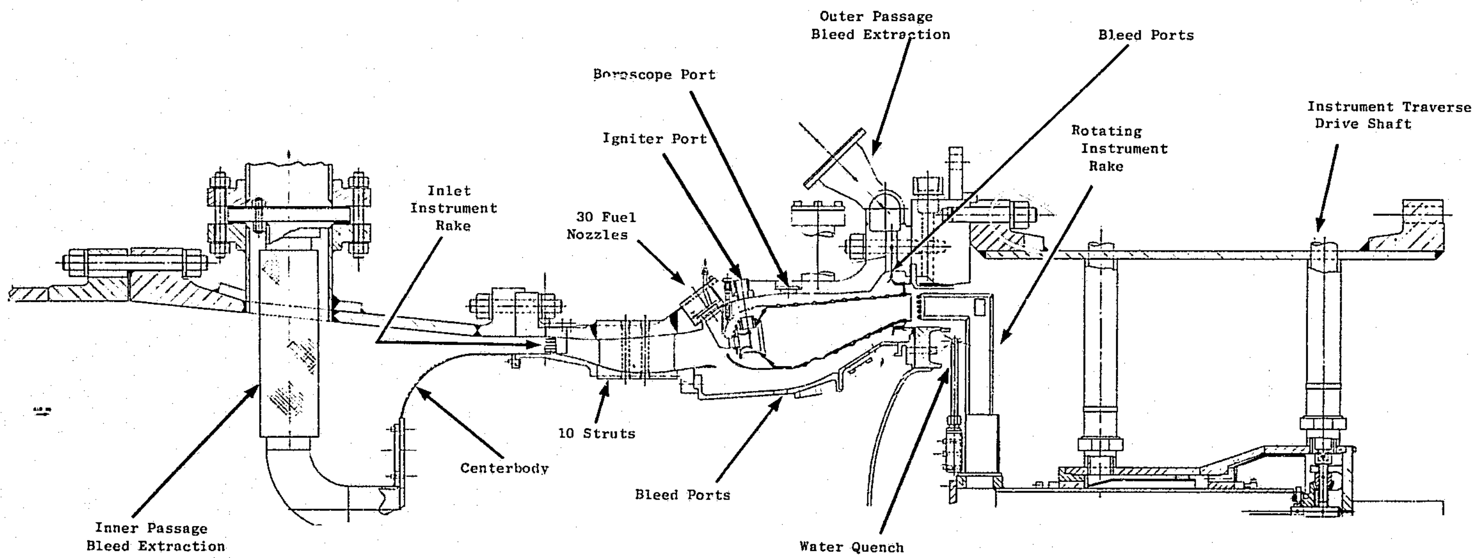
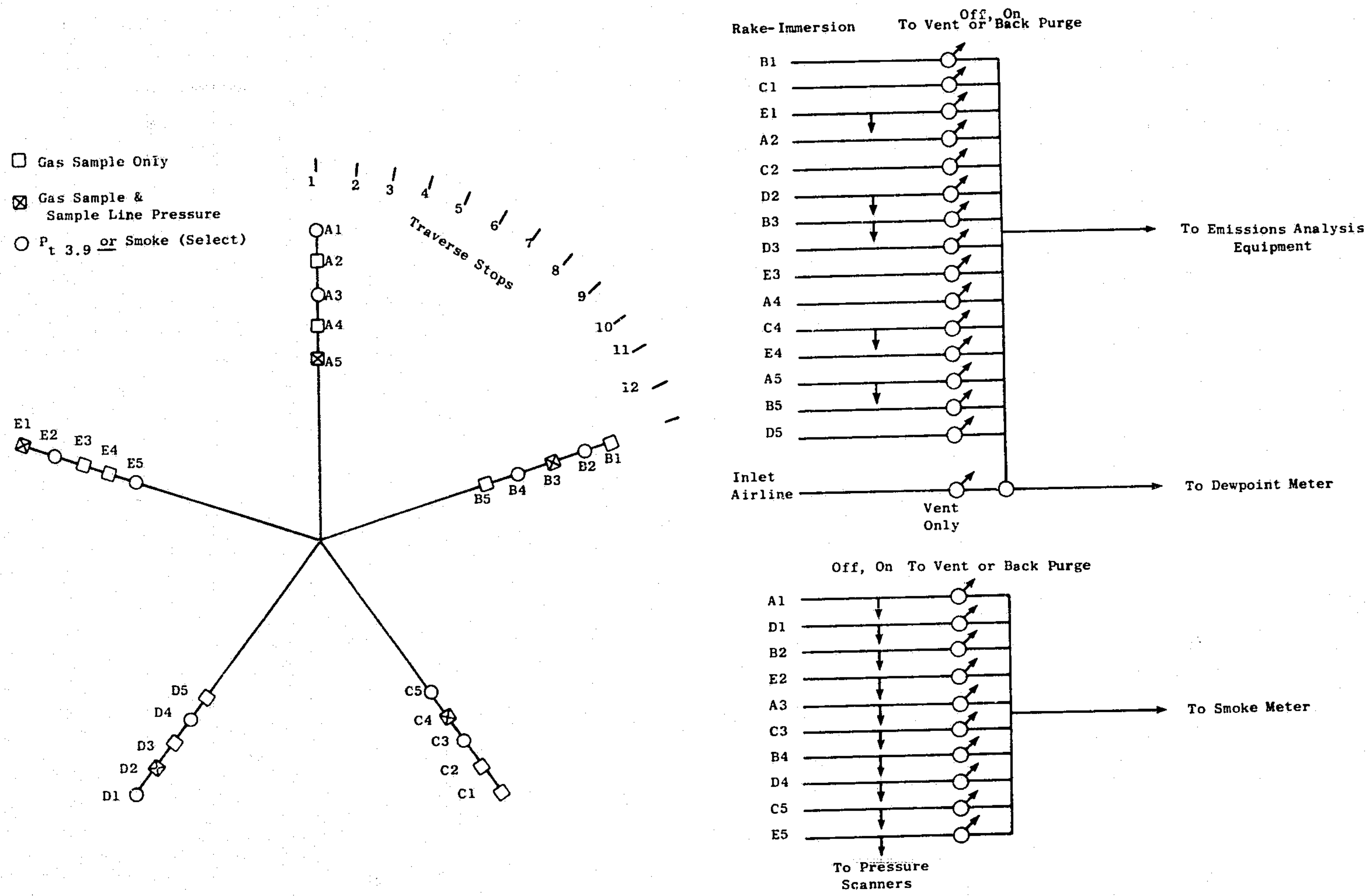


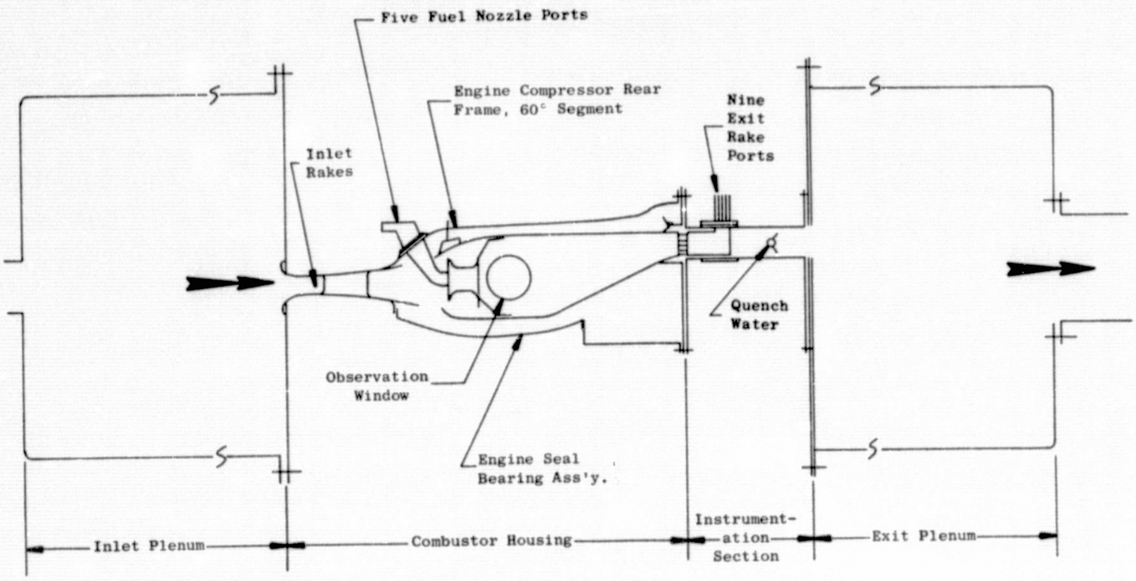
Figure 4. Full Annular CF6-50 Combustor Test Rig, Axial Cross Section View.



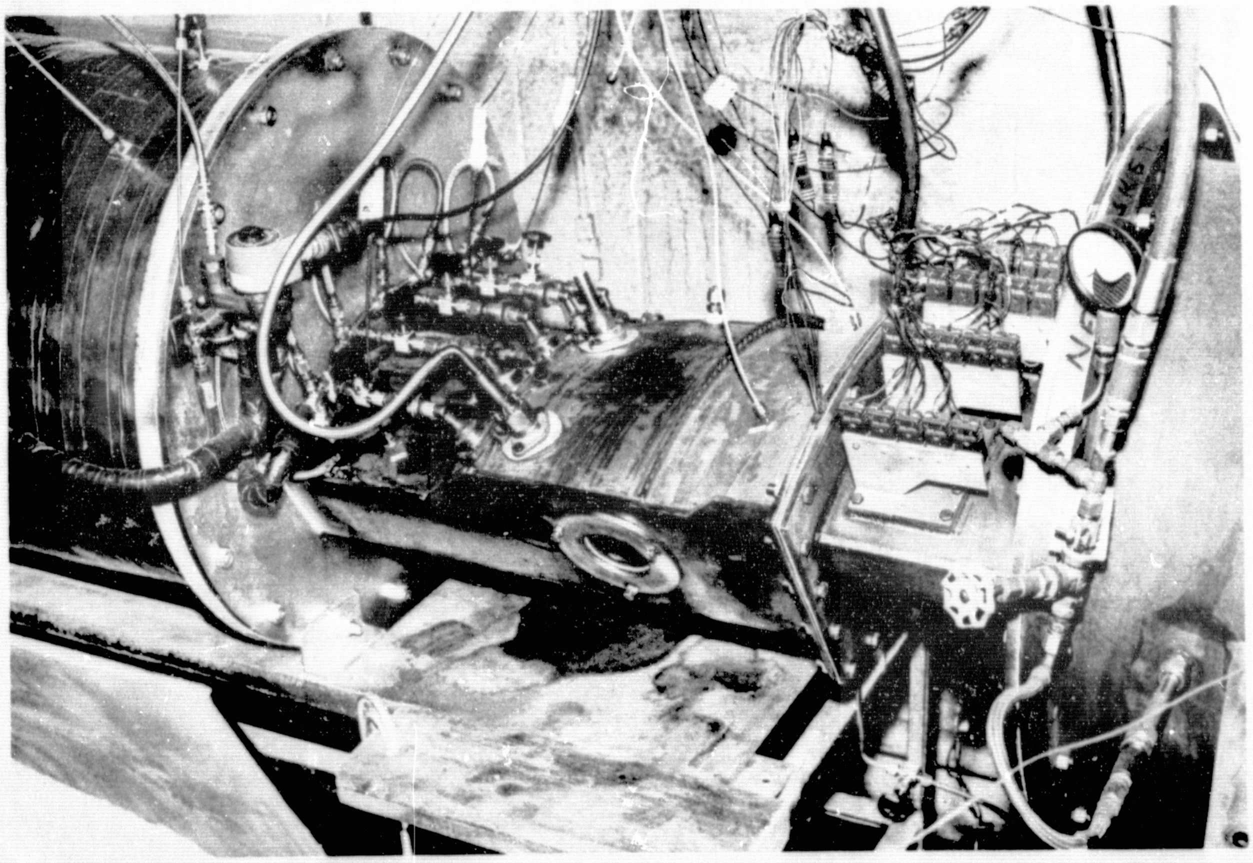
a) Gas Sample Rake Locations, Combustor Exit Plane, Aft Looking Forward

b) Gas Sample Line Line Manifolding Diagram

Figure 5. Gas Sample Location and Manifolding Diagrams.



(a) Test Rig Schematic



(b) Photograph of the Test Rig

Figure 6. CF6-50 60° Sector Combustor Test Rig.

Altitude relight testing was conducted in the Building 301 Small-Scale Combustion Laboratory. This facility has capabilities for testing small combustor rigs over a wide range of simulated altitude relight conditions. Liquid nitrogen heat exchangers are available to independently regulate inlet air and fuel temperatures from ambient down to about 220 K. Steam ejectors in the exhaust ducting can be utilized to reduce inlet air pressure from ambient down to about 0.1 atmospheres.

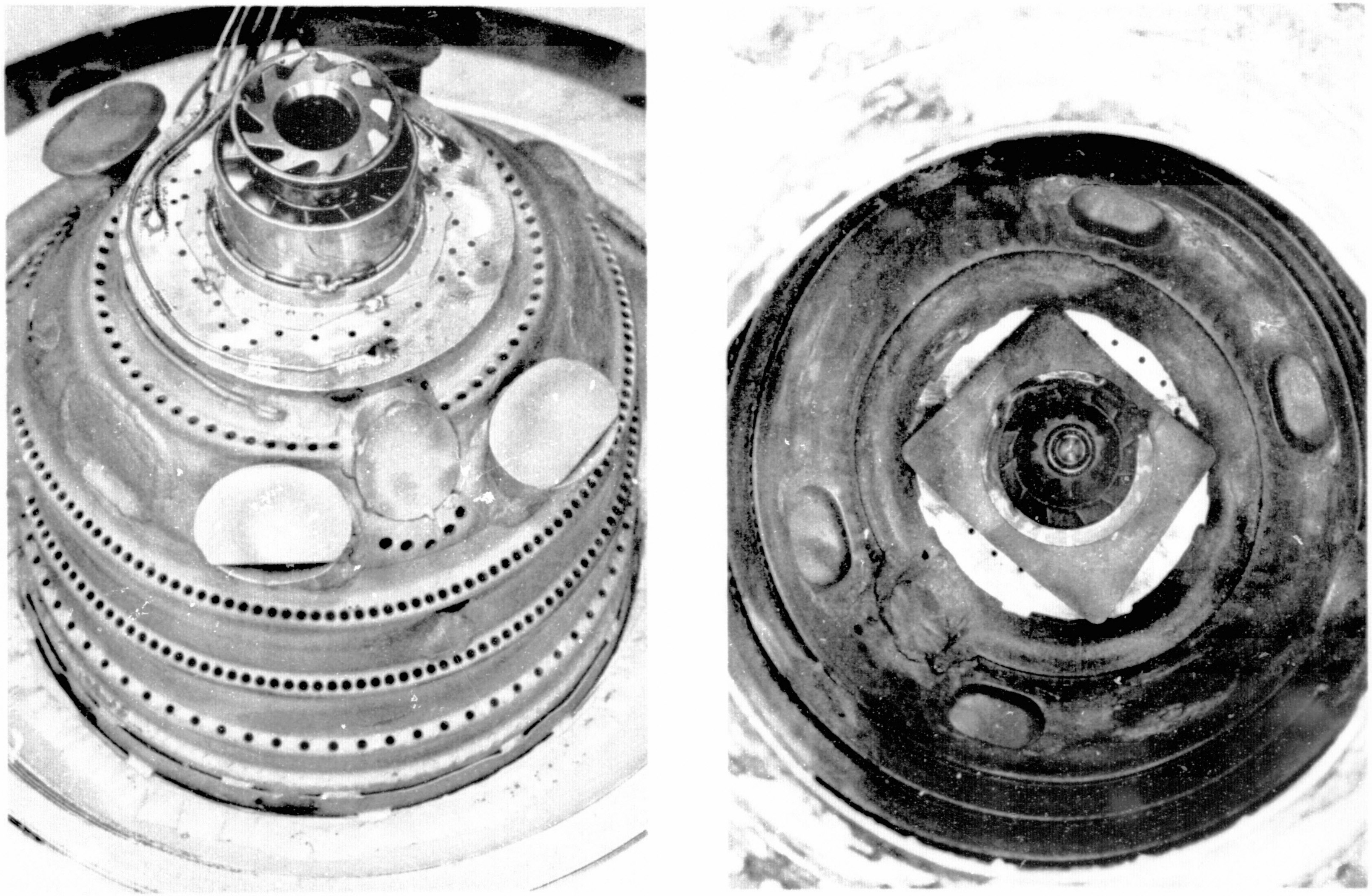
Other 60° sector combustor testing was conducted in the Building 306 Small-Scale Combustion Laboratory. This facility has capabilities for exactly simulating engine idle operating conditions. For idle emissions tests, the sector rig was connected to the facility exhaust ducting for pressure control and the inlet air was heated by an indirect liquid-fueled heat exchanger. Exhaust gas samples were analyzed with an on-line system similar to the one utilized in the full annular combustor tests. For cross-fire tests, the rig was exhausted directly to the atmosphere and the inlet air was heated by vitiation.

12° Sector Rigs

Carboning and flashback development testing was conducted in 12° sector rigs installed in Test Cell A5. This facility has capabilities for testing components at high pressure/temperature conditions. An indirect gas-fired heat exchanger is utilized to heat the inlet air. Nominal air facility limits are 840 K, 18 atmospheres and 5.5 kg/s.

Fuel injector/air swirler carboning tests were conducted to develop configurations suitable for long-time engine operation without harmful carbon buildup. Results are applicable to both stages of the Double Annular Combustor and to the pilot stage of the Radial/Axial Staged Combustor. These development tests were conducted with a simple one-cup sector rig. The fuel injector/air swirler test configurations were each mounted on a can-type combustor as shown in Figure 7 which was then mounted in a 20 cm diameter pipe rig and subjected to a standard high temperature and pressure burning cycle. The test cycle, derived from other previous development programs, was made intentionally severe so that deficiencies in a design would show up after a relatively short time. Success was judged by posttest inspection of the fuel injector and air swirler.

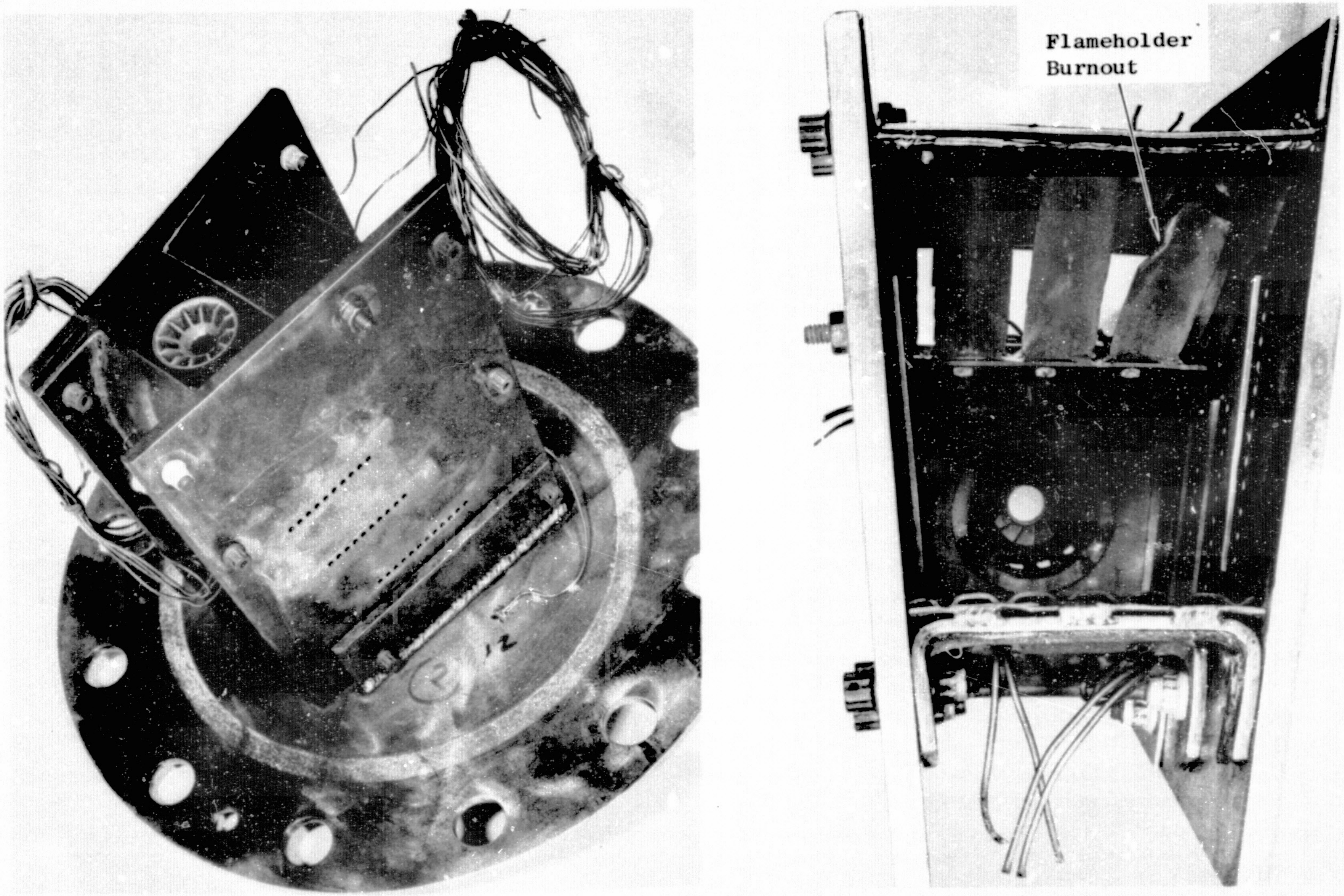
A major concern with the Radial/Axial Staged Combustor is that flashback or upstream burning in the main stage premixing zone may occur under some operating conditions. A 12° sector rig was utilized to investigate this concern. The sector combustor, shown in Figure 8 was installed in the 20 cm diameter pipe rig. The tests consisted of setting increasingly severe operating conditions until flashback was detected or facility limits were reached. The sector was instrumented to measure and continuously record pressure drop, flameholder metal temperatures and air temperatures in the premixing region.



(a) Forward Looking Aft

(b) Aft Looking Forward

Figure 7. 12° Sector Combustor for Carboning Tests.



(a) Forward Looking Aft

(b) Aft Looking Forward

Figure 8. 12° Sector Combustor for Flashback Tests.

COMBUSTOR CONCEPTS

Based on the Phase I Program results, the Double Annular Combustor and Radial/Axial Staged Combustor design approaches were selected for further development in the Phase II Program. Both of these low emissions combustor design approaches feature the use of multi-zone burning to provide proper combustion conditions both at low engine power operating conditions, so that low CO and HC emission levels may be obtained, and at high engine power operating conditions to limit the NO_x emission levels. In both design approaches, all of the fuel is supplied to the pilot stage at low engine power operating conditions. At the higher engine power operating conditions both the pilot and the main stage are fueled. The two design approaches differ in the physical arrangement and design philosophy of the main stage.

Double Annular Combustor

The general arrangement of the Double Annular Combustor design and the full annular development combustor assembly is shown in Figure 9. The combustor consists of a dome assembly, a cowl and modified CF6-50 production combustor cooling liners. The dome assembly consists of two annular arrays of air swirlers (30 in each annulus) which are separated by a short centerbody. The outer annulus is the pilot stage. In the Phase II Program, six features of the basic design were varied:

1. Centerbody geometry
2. Airflow distribution
3. Fuel injector type
4. Air swirler geometry
5. Dilution hole location
6. Intermediate and high power fueling modes

Key design features of each full annular test configuration, together with the design intent of each configuration modification, are summarized in Table IV and Figures 10, 11, 12 and 13. The area/airflow distributions are summarized in Tables V and VI.

Four different secondary swirler configurations were used in the pilot stage development and are shown in Figure 14. The key development feature was the introduction of the secondary mixing barrel in Configuration D5. The main stage swirler configurations are shown in Figure 15. A key development feature as with the pilot stage, was the introduction of the mixing barrel. The three fuel injector assemblies used are shown in Figure 16. Simplex pressure-atomizing fuel nozzles were introduced into both the pilot and main stage in Configuration D4. These were simplex nozzles without an air shroud

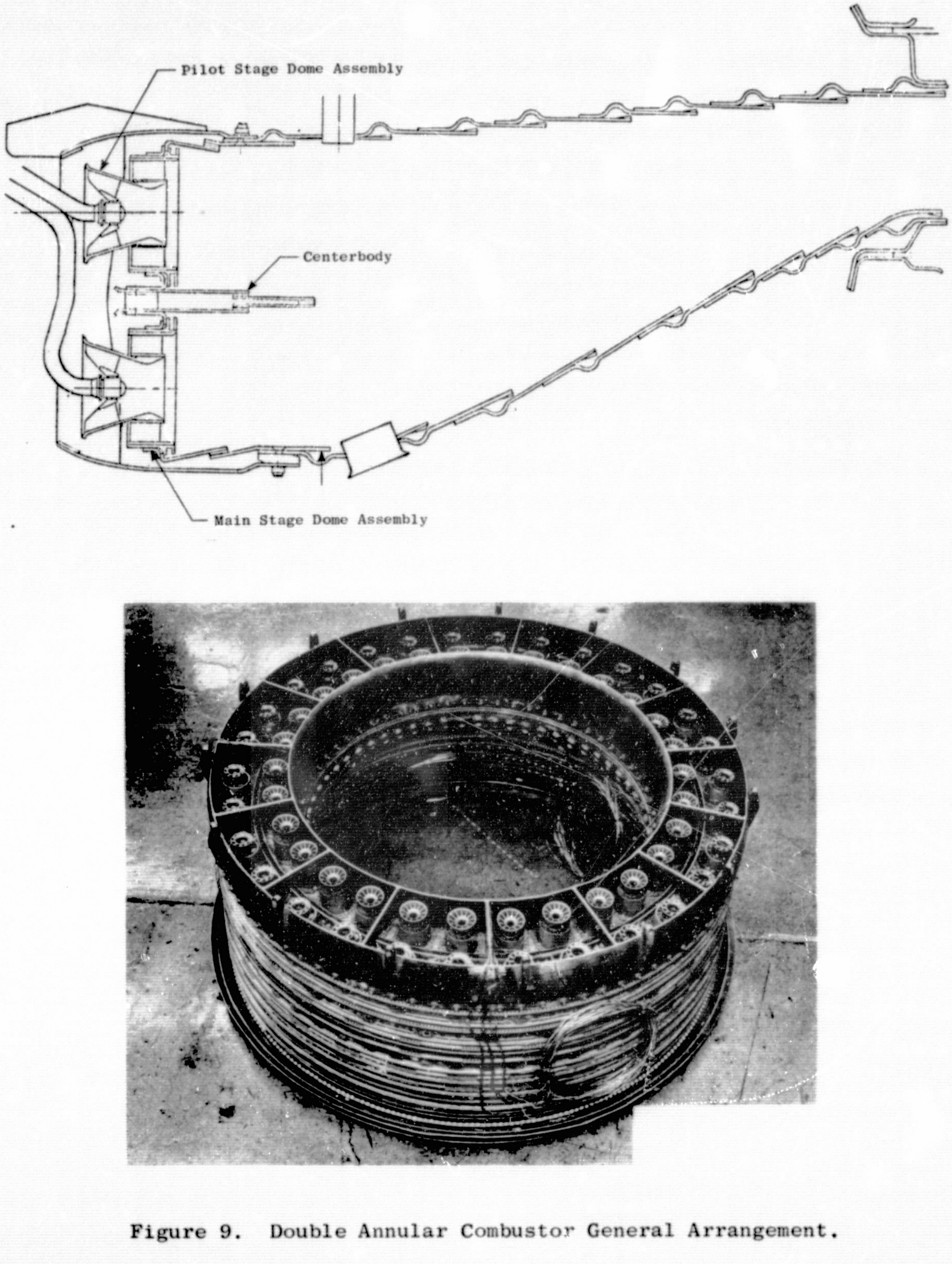


Figure 9. Double Annular Combustor General Arrangement.

Table IV. Double Annular Combustor Test Configurations, Full Annular Rig.

Conf.	Centerbody Length	Crossfire Slot	Fuel Injector		Swirler Mixing Barrels		Dilution Air			Design Intent
			Pilot Stage	Main Stage	Pilot Stage	Main Stage	Outer Liner	Inner Liner	Inner Dome	
II-16	Short	No	Airblast	Airblast	No	No	No	Yes	Yes	Final Phase I Program Configuration
D1	Long	No				No		Yes		Determine the effect of longer centerbody and inner dome dilution holes on emissions
D2	Long					Yes		Yes		Determine the effect of improved inner and outer swirl cup mixing on NO_x
D3	Short							No		Determine the effect of increased inner swirl cup airflow rate on NO_x
D4			Pres. Atomizing	Pres. Atomizing						Determine the effect of fuel nozzles on idle and high power emissions
D5					Yes					Determine the effect of improved outer swirl cup mixing on idle emissions
D6							Yes	Yes	No	Determine the effect of outer liner dilution airflow on idle emissions
D7		Yes							Yes	Determine the effect of alternate inner swirl cup design on high power performance
D8									No	Determine the effect of absence of inner dome dilution on NO_x
D9									No	Determine the effect of increased inner liner dilution airflow on NO_x
D10									Yes	Repeat ~~of D7~~
D11									No	Determine the effect of inner liner dilution airflow distributions on NO_x
D12A			Eng. Prototype	Not Fueled						Determine the effect of engine prototype pilot swirlers and fuel nozzles on idle emission
D12B			Pres. Atomizing	Pres. Atomizing						Determine the effect of inner liner dilution airflow distribution on NO_x
D13										Determine the effect of increased inner liner dilution and air penetration on NO_x
D14A										Determine the effect of reduced inner liner dilution air penetration on NO_x
D14B			Eng. Prototype	Not Fueled						Determine the effect of increased pilot stage dilution and cooling airflow on idle emissions with engine prototype nozzles

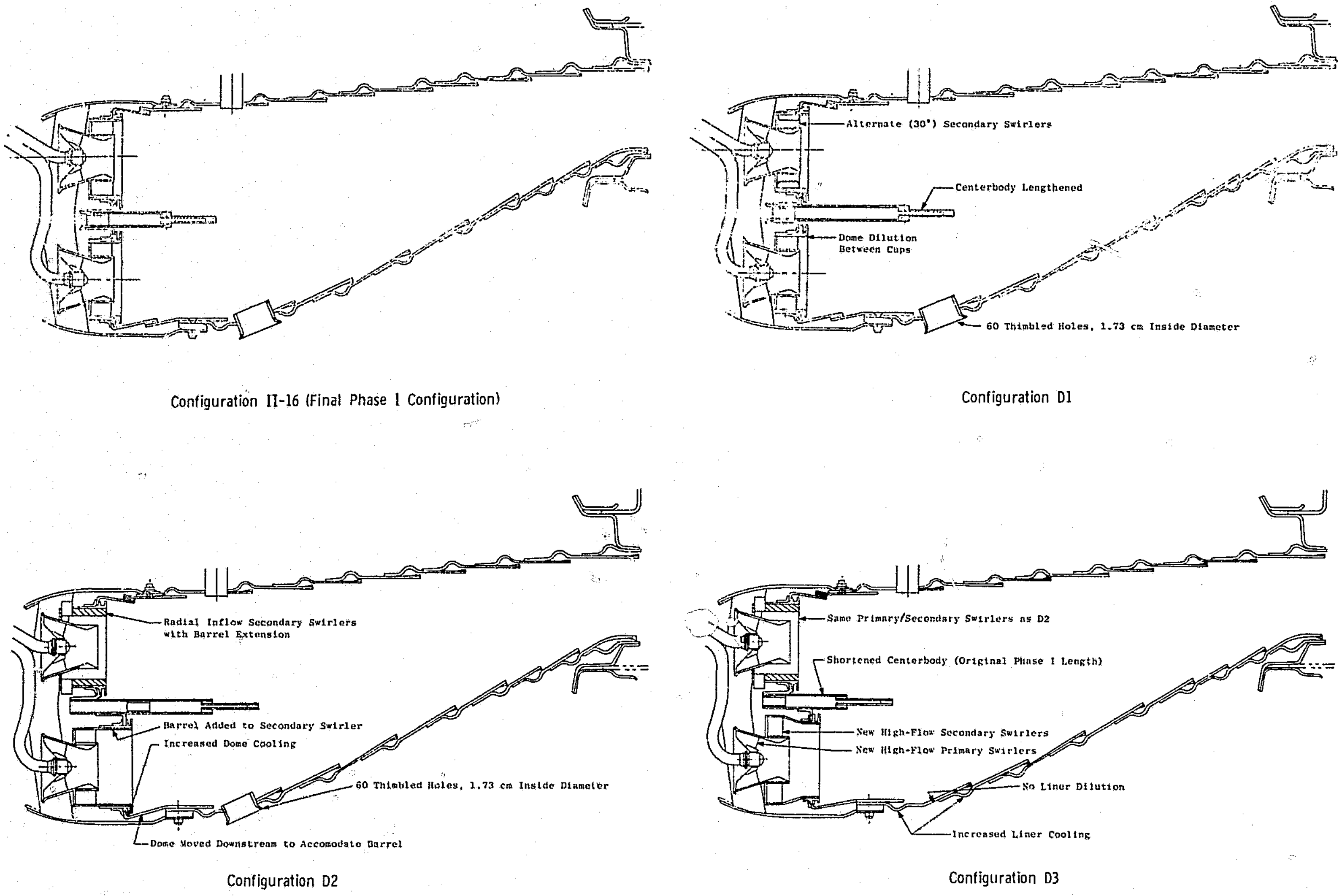


Figure 10. Double Annular Combustor Design Parameter Variations, Configurations II-16 - D3.

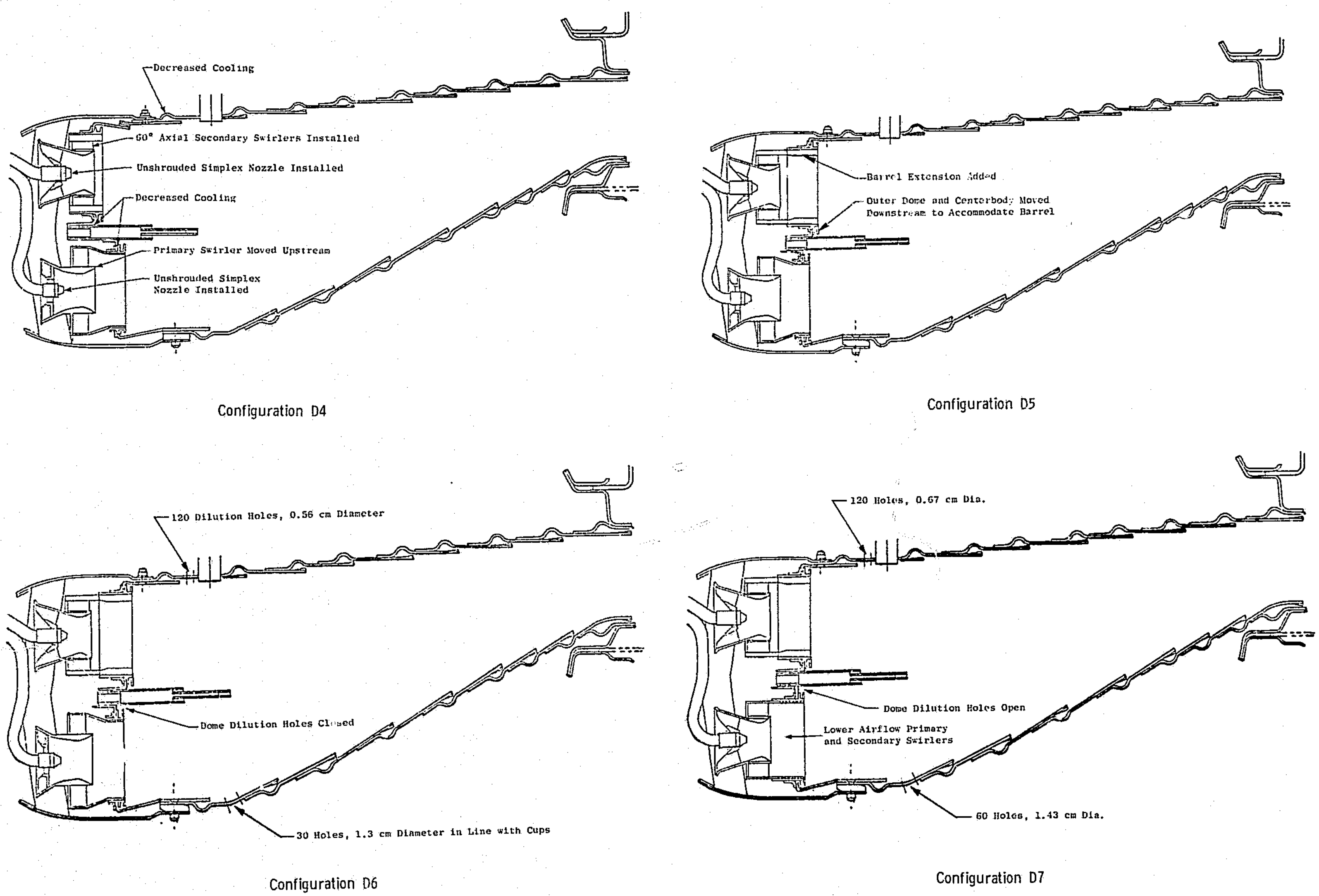


Figure 11. Double Annular Combustor Design Parameter Variations, Configurations D4 - D7.

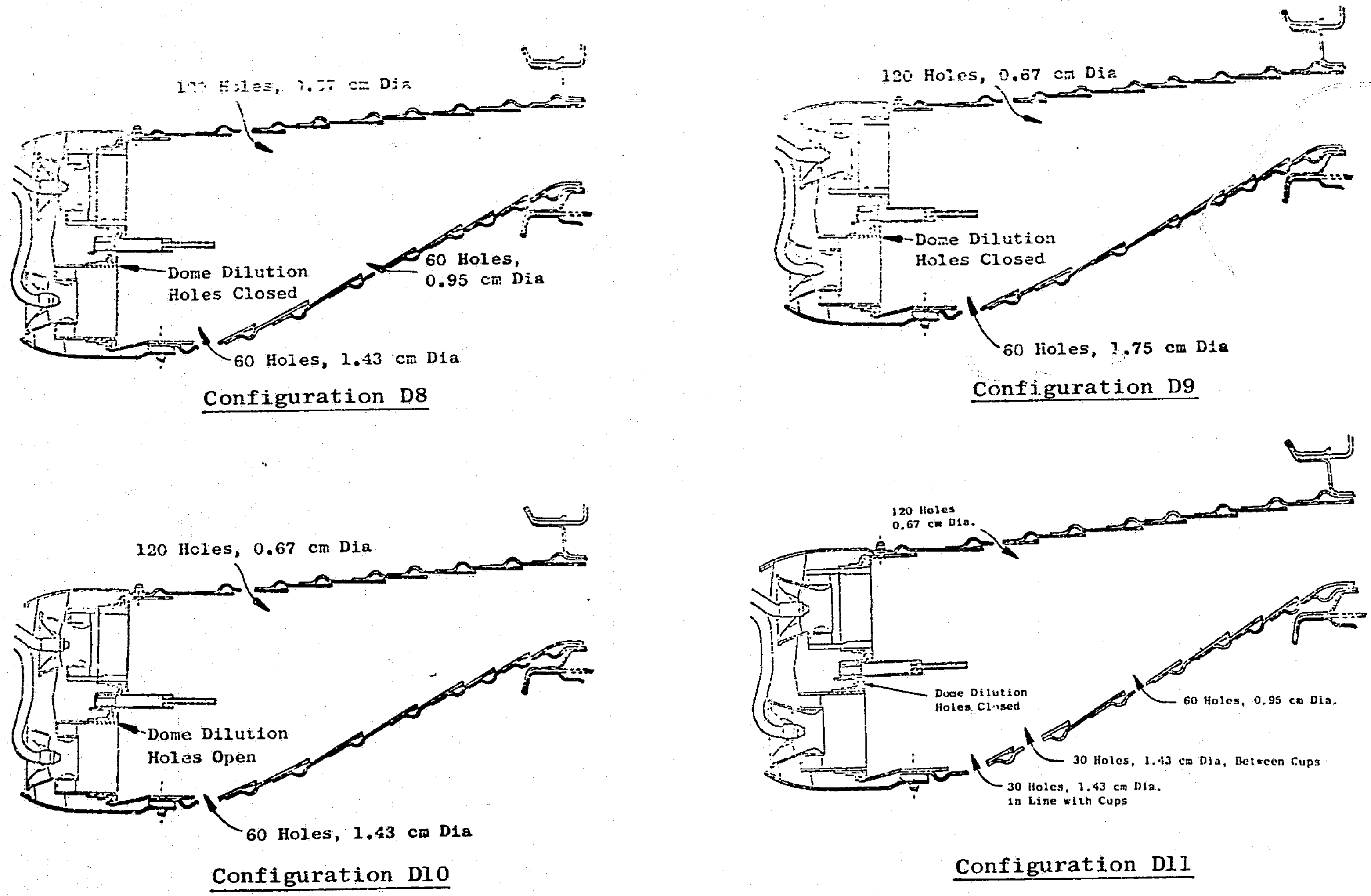


Figure 12. Double Annular Combustor Design Parameter Variations. Configurations D8 - D11.

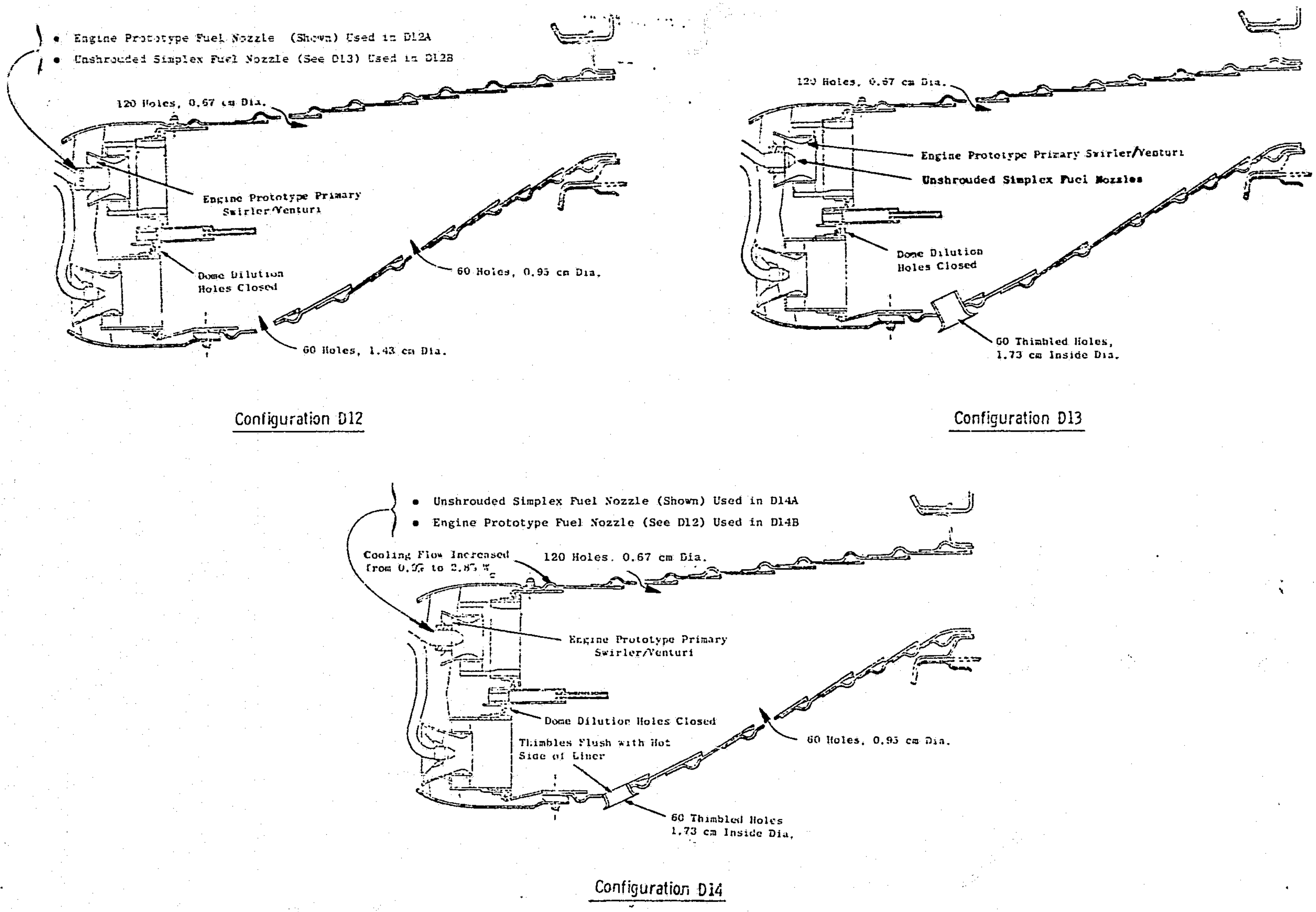


Figure 13. Double Annular Combustor Design Parameter Variations, Configurations D12 - D14.

Table V. Double Annular Combustor, Area/Airflow Distributions, Full Annular Test Configurations D1 - D7.

Configuration	D1		D2		D3		D4		D5		D6		D7	
	A_e, cm^2	$\%W_c$	A_e, cm^2	$\%W_c$	A_e, cm^2	$\%W_c$	A_e, cm^2	$\%W_c$	A_e, cm^2	$\%W_c$	A_e, cm^2	$\%W_c$	A_e, cm^2	$\%W_c$
Outer Swirl Cups														
Fuel nozzle shroud	5	0.9	5	0.9	5	0.9	0.5	0.1	0.5	0.1	0.5	0.1	0.5	0.1
Primary swirler	19	3.5	19	3.6	19	3.6	19	3.7	19	3.6	19	3.5	19	3.6
Secondary swirler	48	8.8	38	7.1	38	7.2	47	9.0	47	9.0	47	8.8	47	8.8
Total	72	13.2	62	11.6	62	11.7	66.5	12.8	66.5	12.7	66.5	12.4	66.5	12.5
Inner Swirl Cups														
Fuel nozzle shroud	5	0.9	5	0.9	5	0.9	0.5	0.1	0.5	0.1	0.5	0.1	0.5	0.1
Primary swirler	19	3.5	19	3.6	50	9.5	50	9.6	50	9.6	50	9.3	19	3.6
Secondary swirler	158	29.1	158	29.6	202	38.3	202	39.0	202	38.6	202	37.6	158	29.8
Total	182	33.5	182	34.1	257	48.7	252.5	48.7	252.5	48.3	252.5	47.0	177.5	33.5
Dilution														
Outer liner - Panel 1	0	0	0	0	0	0	0	0	0	0	17	3.2	25	4.7
- Panel 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Inner dome	26	4.8	26	4.9	26	4.9	26	5.0	26	5.0	0	0	26	4.9
Inner liner - Panel 1	92	16.9	92	17.3	0	0	0	0	0	0	23	4.3	58	10.9
- Panel 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
- Panel 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	118	21.7	118	22.2	26	4.9	26	5.0	26	5.0	40	7.5	109	20.5
Cooling														
Outer liner	42	7.7	42	7.9	40	7.6	39	7.5	43	8.2	43	8.0	43	8.1
Outer dome	28	5.1	28	5.3	28	5.3	24	4.6	24	4.6	24	4.5	24	4.5
Centerbody	21	3.9	21	3.9	21	4.0	21	4.1	21	4.0	21	3.9	21	4.0
Inner dome	27	5.0	26	4.9	26	4.9	22	4.2	22	4.2	22	4.1	22	4.1
Inner liner	46	8.4	46	8.6	60	11.4	60	11.6	60	11.5	60	11.1	60	11.3
Seal leakage	8	1.5	8	1.5	8	1.5	8	1.5	8	1.5	8	1.5	8	1.5
Total	172	31.6	171	32.1	183	34.7	174	33.5	178	34.0	178	33.1	178	33.5
Combustor Total	544	100.0	533	100.0	528	100.0	519	100.0	523	100.0	537	100.0	531	100.0

Table VI. Double Annular Combustor, Area/Airflow Distributions, Full Annular Test Configurations D8 - D14.

Configuration	D8		D9		D10		D11		D12A		D12B		D13		D14A		D14B	
	A_e, cm^2	$\%W_c$	A_e, cm^2	$\%W_c$	A_e, cm^2	$\%W_c$	A_e, cm^2	$\%W_c$	A_e, cm^2	$\%W_c$	A_e, cm^2	$\%W_c$	A_e, cm^2	$\%W_c$	A_e, cm^2	$\%W_c$	A_e, cm^2	$\%W_c$
Outer Swirl Cups																		
Fuel nozzle shroud	1	0.1	1	0.1	1	0.1	1	0.1	5	0.9	1	0.1	1	0.1	1	0.1	5	0.8
Primary swirler	19	3.6	19	3.6	19	3.6	19	3.6	28	5.2	28	5.3	28	5.1	28	4.8	28	4.6
Secondary swirler	47	8.8	47	8.8	47	8.8	47	8.8	39	7.3	39	7.3	39	7.3	39	6.7	39	6.5
Total	67	12.5	67	12.5	67	12.5	67	12.5	72	13.4	68	12.7	68	12.5	68	11.6	72	11.9
Inner Swirl Cups																		
Fuel nozzle shroud	1	0.1	1	0.1	1	0.1	1	0.1	1	0.1	1	0.1	1	0.1	1	0.1	19	3.2
Primary swirler	19	3.6	19	3.6	19	3.6	19	3.6	19	3.5	19	3.6	19	3.5	19	3.3	19	3.1
Secondary swirler	158	29.8	158	29.6	158	29.8	158	29.7	158	29.5	158	29.7	158	29.3	158	27.1	158	26.1
Total	178	33.5	178	33.3	178	33.5	178	33.4	178	33.1	178	33.4	178	32.9	178	30.5	196	32.4
Dilution																		
Outer liner - Panel 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
- Panel 2	25	4.7	25	4.7	25	4.7	25	4.7	25	4.7	25	4.7	25	4.6	29	5.0	29	4.8
Inner dome	0	0	C	0	26	4.9	0	0	0	0	0	0	0	0	0	0	0	0
Inner liner - Panel 1	58	10.9	86	16.1	58	10.9	29	5.5	58	10.8	58	10.9	92	17.0	92	15.8	92	15.2
- Panel 2	0	0	0	0	0	0	29	5.5	0	0	0	0	0	0	0	0	0	0
- Panel 4	26	4.9	0	0	0	0	26	4.9	26	4.8	26	4.9	0	0	26	4.5	26	4.3
Total	109	20.5	111	20.8	109	20.5	109	20.6	109	20.3	109	20.5	117	21.6	147	25.3	147	24.3
Cooling																		
Outer liner	43	8.1	43	8.1	43	8.1	43	8.1	43	8.0	43	8.1	43	8.0	55	9.4	55	9.1
Outer dome	24	4.5	24	4.5	24	4.5	24	4.5	24	4.5	24	4.5	24	4.4	24	4.1	24	4.0
Centerbody	21	4.0	21	3.9	21	4.0	21	4.0	21	3.9	21	3.9	21	3.9	21	3.6	21	3.5
Inner dome	22	4.1	22	4.1	22	4.1	22	4.1	22	4.1	22	4.1	22	4.1	22	3.8	22	3.6
Inner liner	60	11.3	60	11.3	60	11.3	60	11.3	60	11.2	60	11.3	60	11.1	60	10.3	60	9.9
Seal leakage	8	1.5	8	1.5	8	1.5	8	1.5	8	1.5	8	1.5	8	1.5	8	1.4	8	1.3
Total	178	33.5	178	33.4	178	33.5	178	33.5	178	33.2	178	33.4	178	33.0	190	32.6	190	31.4
Combustor Total	532	100.0	534	100.0	532	100.0	532	100.0	537	100.0	533	100.0	541	100.0	583	100.0	605	100.0

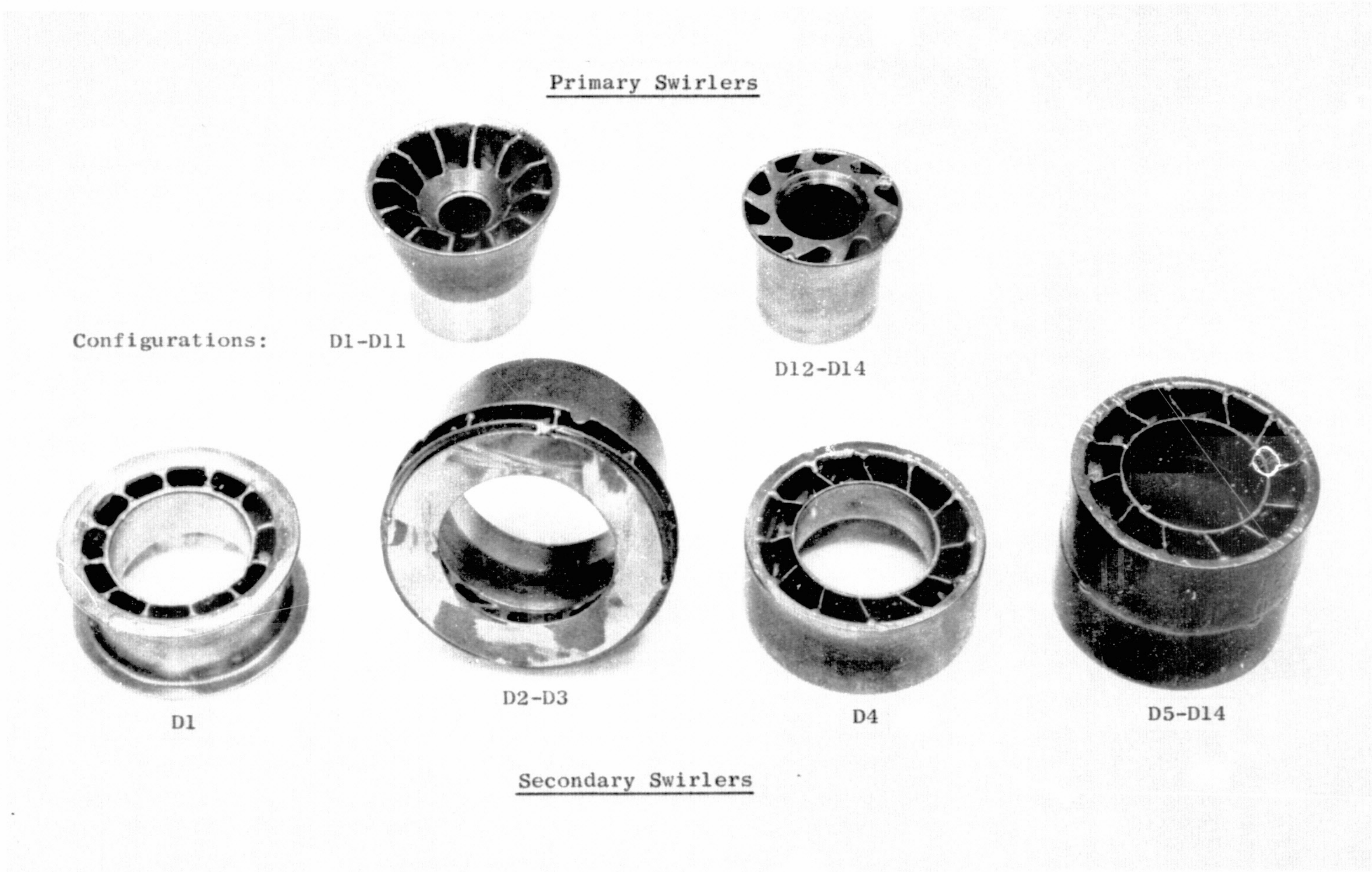


Figure 14. Pilot Stage Air Swirler Configurations, Double Annular Combustor.

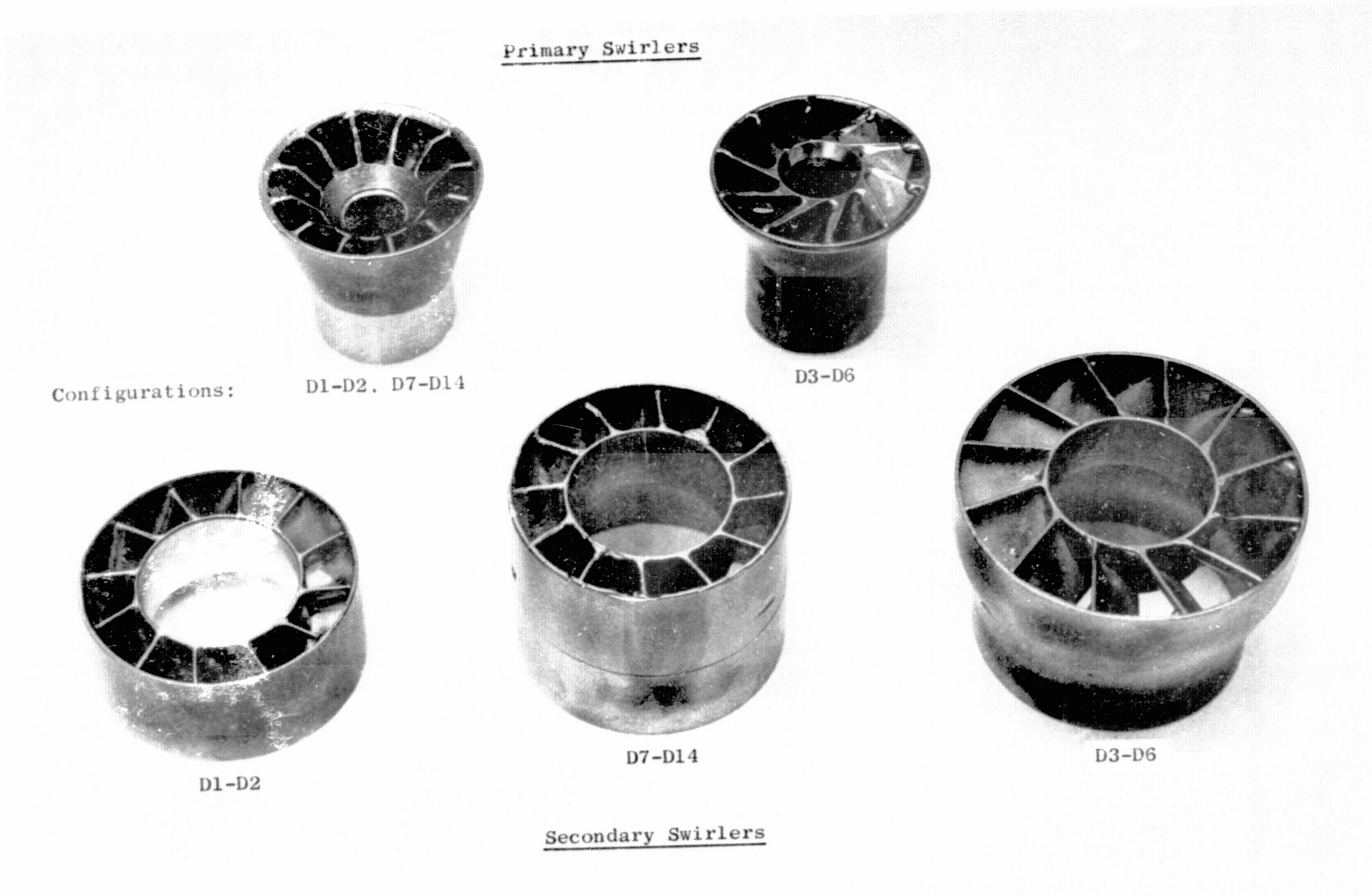
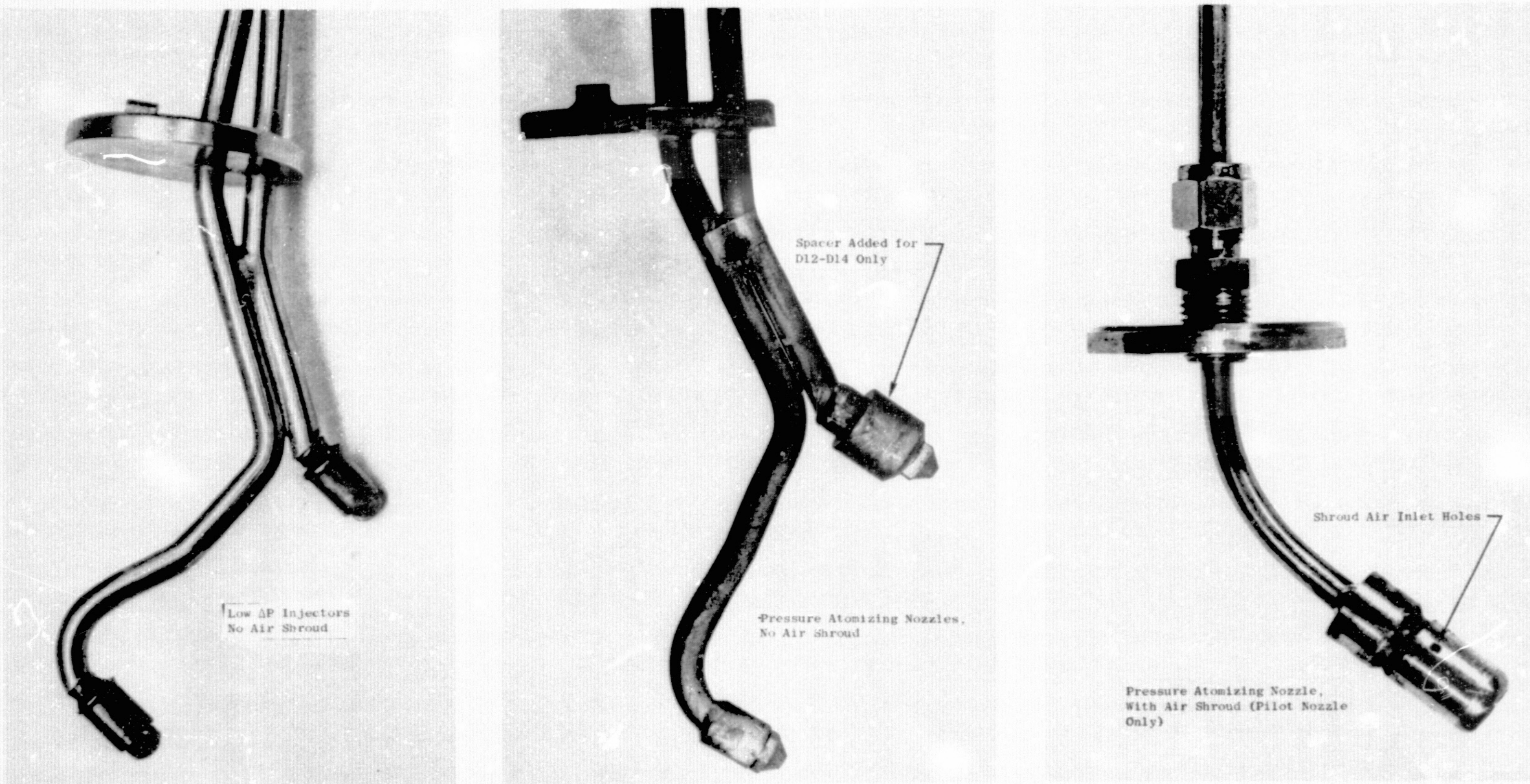


Figure 15. Main Stage Air Swirler Configurations, Double Annular Combustor.



Configurations D1 - D3

Configurations D4 - D11, D12B, D13, D14A

Configurations D12A, D14B

Figure 16. Fuel Injector Configurations, Double Annular Combustor.

to prevent carbon buildup on the nozzle tip. Engine prototype fuel nozzles, introduced into the pilot stage of Configuration D12A, and D14B, did have an air shroud and closely simulated the spray characteristics of the engine design. A number of different fueling modes were investigated in both the Double Annular and Radial/Axial Staged Combustor development tests. The fueling modes explored on both combustors are summarized in Table VII.

A 60° Double Annular Combustor sector, shown in Figure 17, which was identical to the full annular combustor, was used to screen promising design variations. Fifteen altitude relight test configurations and 12 idle emission test series are shown in Table VIII. Fifteen cross-fire test configurations were also evaluated and key design feature variations in this test series are shown in Table IX and Figure 18.

The 12° sector combustor rig was utilized in parallel with the full annular and 60° sector rigs for carboning development. Eight 12° sector test configurations were evaluated. Key design feature variations are shown in Table X.

Radial/Axial Staged Combustor

The general arrangement of the Radial/Axial Staged Combustor design approach, and the full annular development combustor assembly are shown in Figure 19. The combustor assembly consists of a cowl, a pilot stage dome assembly, a main stage flameholder assembly, and modified CF6-50 production combustor cooling liners. The pilot stage dome assembly consists of an array of air swirlers similar to those in the Double Annular Combustor. The main stage flameholder assembly consists of an array of sloping high blockage flameholders which are located radially outward from, and aft of, the pilot stage combustion zone. Main stage fuel is injected into the annular duct upstream of the flameholder array so that a carbureted fuel-air mixture is admitted through the slots between flameholders. The base of each flameholder is open to permit the pilot stage combustion products to flow radially outward in the flameholder wakes and pilot the main stage combustion process. In the Phase II Program, six features of the basic design were varied:

1. Airflow distribution
2. Pilot stage fuel injector type
3. Dilution air hole location
4. Number of flameholders
5. Main stage fuel injection point
6. Intermediate and high power fueling modes.

Table VII. Fueling Modes, Full Annular Rig Tests.

Combustor Type	Operating Condition	Fueling Patterns Tested: Pilot Stage Injectors	Fueling Patterns Tested: Main Stage Injectors	Ranges of Fuel Splits Tested (Pilot Fuel Flow/Total Fuel Flow)
Double Annular	Idle	Uniform	Not fueled	1.00
	Approach	Uniform	a) Not fueled b) Uniform c) Alternate d) 180° sector	0 to 1.00
	Cruise	Uniform	Uniform	0.15 to 0.60
	Climbout	Uniform	Uniform	0.12 to 0.48
	Takeoff	Uniform	Uniform	0 to 0.45
Radial/Axial Staged	Idle	a) Uniform b) Alternate	Not fueled	1.00
	Approach	a) Uniform b) Alternate	a) Not fueled b) Alternate	0.28 to 1.00
	Cruise	Uniform	a) Not fueled b) Uniform c) Alternate	0.22 to 1.00
	Climbout	Uniform	a) Uniform b) Alternate	0.18 to 0.45
	Takeoff	a) Uniform b) Alternate	Uniform	0.13 to 0.34

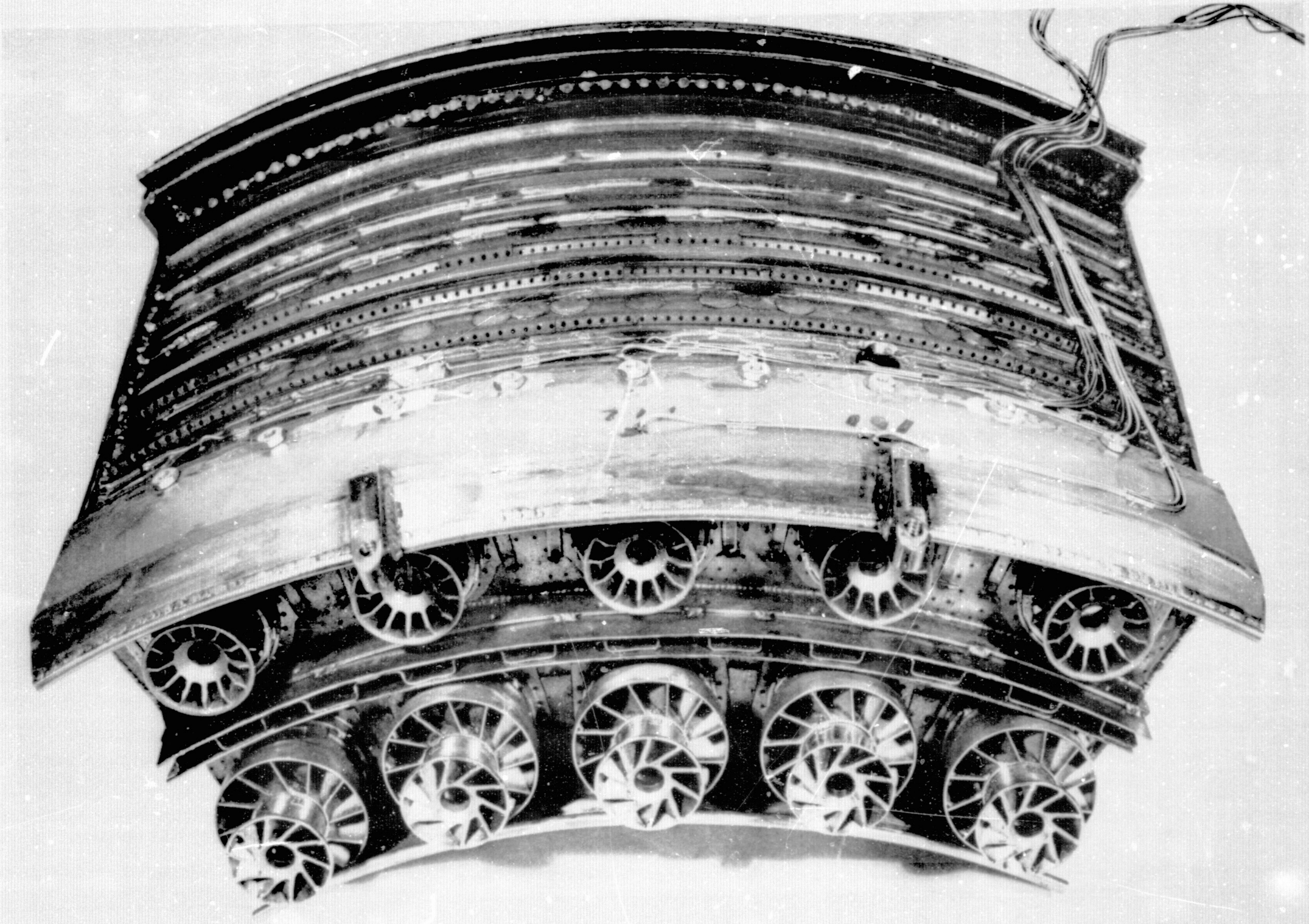


Figure 17. Double Annular Sector Combustor Assembly.

Table VIII. Double Annular Combustor Test Configurations, 60° Sector Rig.

Altitude Relight Studies

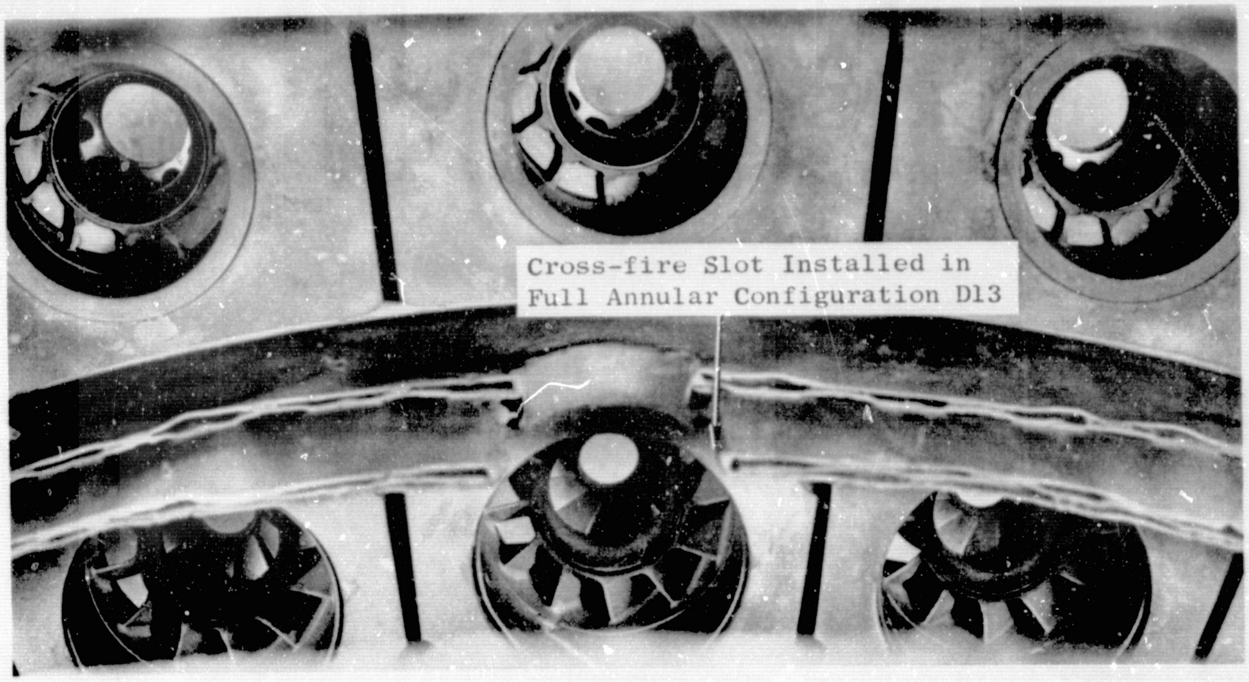
Configurations	Key Design Features Explored
DS1A	Baseline test. Airblast fuel injectors.
DS1B, DS2A thru D	Fuel atomization investigation. Nozzle flow rates range from 9.1 to 45.5 kg/hr at 6.8 atmospheres
DS3, DS4	Alternate swirler configuration.
DS5A thru D	Effect of fuel atomization in combination with pilot stage mixing barrels.
DS19 thru DS25 DS28 thru DS30	Effect of amount and distribution of pilot stage and/or main stage dilution airflow.

Idle Emission Studies

Configurations	Key Design Features Explored
DS3 thru DS7	Pilot stage fuel nozzle/swirler combinations including pilot stage mixing barrels.
DS31A thru D DS32A and B DS33A thru E	Pilot stage fuel nozzle atomization/spray angle, nozzle shroud airflow, nozzle axial immersion, first outer panel cooling airflow, fuel nozzle/swirl cup radial positioning.
DS34, DS35 thru DS38	Amount and distribution of pilot stage dilution airflow. Effect of aft profile trim airflow.

Table IX. Double Annular Combustor Cross-fire Test Configurations, Main Stage Airflow Investigation, 60° Sector Rig.

Configuration	Key Design Features Explored
DS8	High flow inner swirlers; first panel inner dilution (like full annular D6)
DS9	High flow inner swirlers; no first panel dilution
DS10	Low flow inner secondary swirlers; no first panel dilution
DS11	High flow inner primary swirlers; first panel dilution (like DS8)
DS12	High flow inner primary swirlers; second panel dilution
DS13	Low flow inner primary swirlers; second panel dilution
DS14	Low flow inner primary swirlers; first panel dilution
DS15	High flow inner primary and secondary swirlers; first panel dilution
DS16	Low flow inner swirlers, dome holes; increased first panel dilution
DS17	Same as DS16 but with cross-fire slot
DS18	Similar to DS16 but with dome holes closed, cross-fire slot



Configuration	Cross-Fire Slot Dimensions, cm	
	Width	Length (Axial)
Sector:		
DS22	0	0
DS25	2.5	3.9
DS26	2.5	2.7
DS27	1.2	3.9
Annular:		
D1-D6	0	0
D7-D14	2.5	3.9

Figure 18. Cross-Fire Slot Configurations, Double Annular Combustor.

Table X. 12° Sector Combustor Test Configurations.

Pilot Stage Carboning Configurations								
Configurations	CS2	CS3	CS4	CS5	CS6	CS7	CS8	CS9*
A_{es}/A_T	0.188	0.275	0.322	0.387	0.322	0.386	0.314	0.358
L_T/D_T	0.80	0.76	1.12	0.76	0.59	0.59	0.59	0.59

*Selected design.

Radial/Axial Staged Combustor Configurations			
Configurations	FS1	FS2	FS3
No. of main stage flameholders	60	120	120
Main stage airflow (% Wc)	61	52	52
Main stage premix length	Long	Long	Long

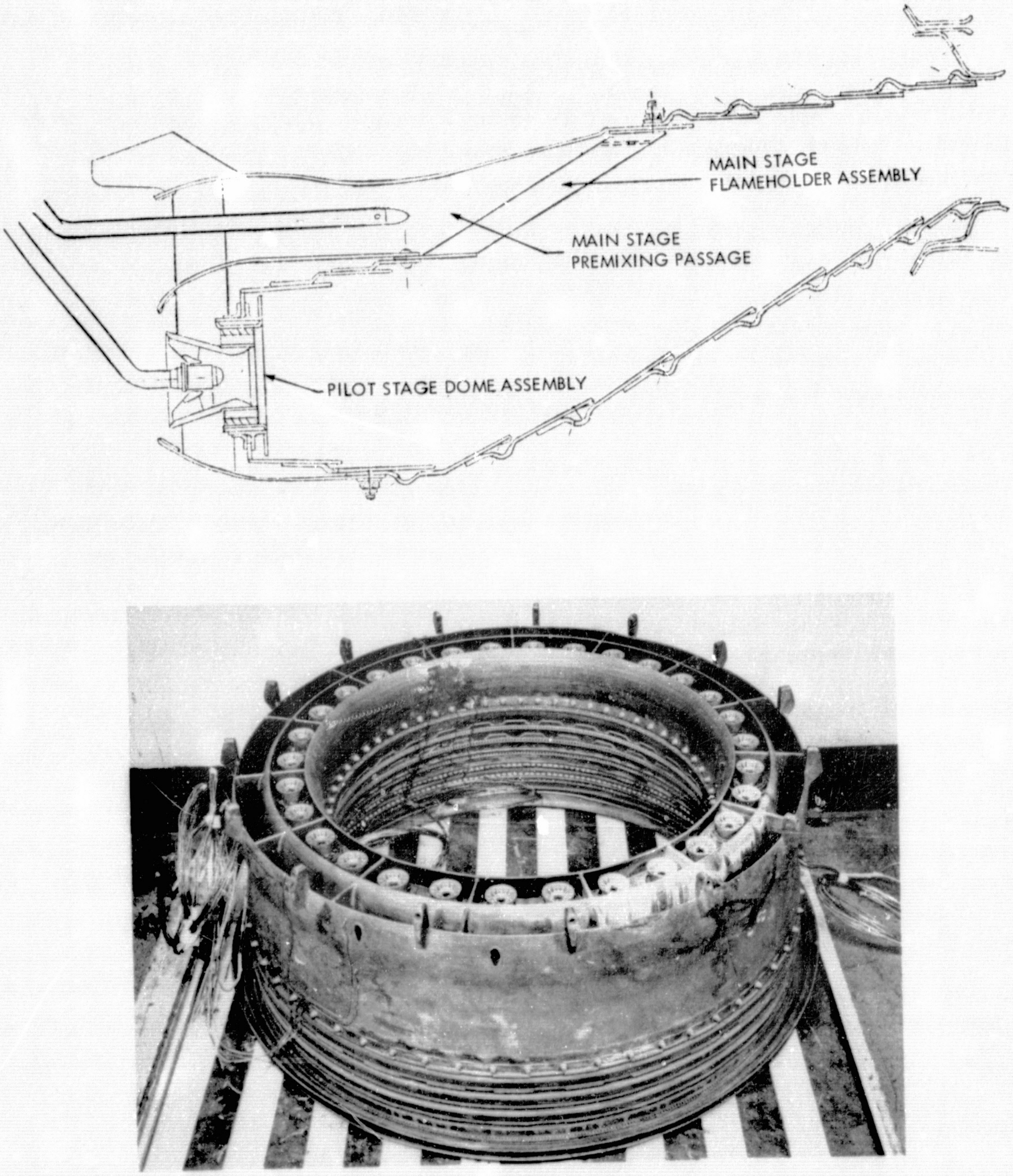


Figure 19. Radial/Axial Staged Combustor General Arrangement.

Key design features of each full annular test configuration, together with the design intent of each configuration modification, are summarized in Table XI and Figures 20 and 21. The area/airflow distributions are summarized in Table XII.

A 60° sector combustor, shown in Figure 22, identical to the full annular combustor was utilized for altitude relight development. Three configurations were evaluated. Key design feature variations in these tests are shown in Table XIII.

Three 12° sector combustor configurations were flashback tested. Key design feature variations are shown in Table X.

TEST CONDITIONS AND PROCEDURES

Full Annular Performance/Emission Tests

The test conditions represented actual engine operating conditions, simulated engine operating conditions and parametric variations about these operating conditions. The most important test points are the CF6-50 engine standard day idle and takeoff conditions since the program goals for emissions and performance are specified at these cycle points. Other points of particular interest are the EPA-defined approach (30% power) and climbout (85% power) operating modes and the standard day cruise condition. A summary of the combustor operating conditions is presented in Table III.

Combustor inlet temperatures, reference velocities and turbine cooling air extraction rates of the CF6-50 engine were exactly duplicated. Combustor inlet pressure levels were duplicated at the idle condition, but reduced pressure levels, relative to those of the engine, consistent with the test facility air supply capacity were tested at the higher power conditions. Airflow and fuel flow rates of Table III were correspondingly reduced to simulate the true combustor reference velocities and fuel-air ratios. At the takeoff condition, the test pressure was 9.5 atm., compared to the engine pressure of 29.8 atm.

Selected combustor configurations were tested over a range of combustor inlet pressures at the high power operating modes to evaluate the effects of pressure on emission levels. These effects were required to extrapolate the emission levels measured at the reduced pressure rig test conditions to the higher pressure levels encountered in the CF6-50 engine. The range of pressures evaluated during the Phase II tests were:

	P_3
Idle	2.9 atm.
Approach	3.4 - 6.8 atm.
Cruise	4.8 - 9.5 atm.
Climbout	4.8 - 9.5 atm.
Takeoff	3.1 - 9.5 atm.

Table XI. Radial/Axial Staged Combustor Test Configurations, Full Annular Rig.

	Main Stage				Pilot Stage		
Config.	No. of Flameholders	Premix Length	Radial Flow Splitter	Turning Vanes	Fuel Injectors	Liner Dilution	Design Intent
R1	60	Short	No	Yes	Airblast	No	Determine the effect of circumferential fuel staging on emissions
R2	60		Yes	Yes			Determine the effect of radial fuel staging on emissions
R3	120		No	No			Determine the effect of increased wetted perimeter on main stage emissions
R4	120	Long	No	No	Pressure Atomizing (1)		Determine the effect of fuel nozzles on pilot stage idle emissions and increased main stage premix on high power emissions
R5	120		No	Yes			Determine the effect of main stage richness on emissions
R6	60		Yes	Yes		Yes	Determine the effect of pilot stage dilution on idle emissions and radial fuel staging on high power emissions
R7	120	Short	No	No		Yes	Determine the effect of reduced main stage premix and increased main stage wetted perimeter on emissions

(1) Simplex fuel nozzles with 9.5 kg/hr @ 6.8 atm; 70° spray angle - unshrouded.

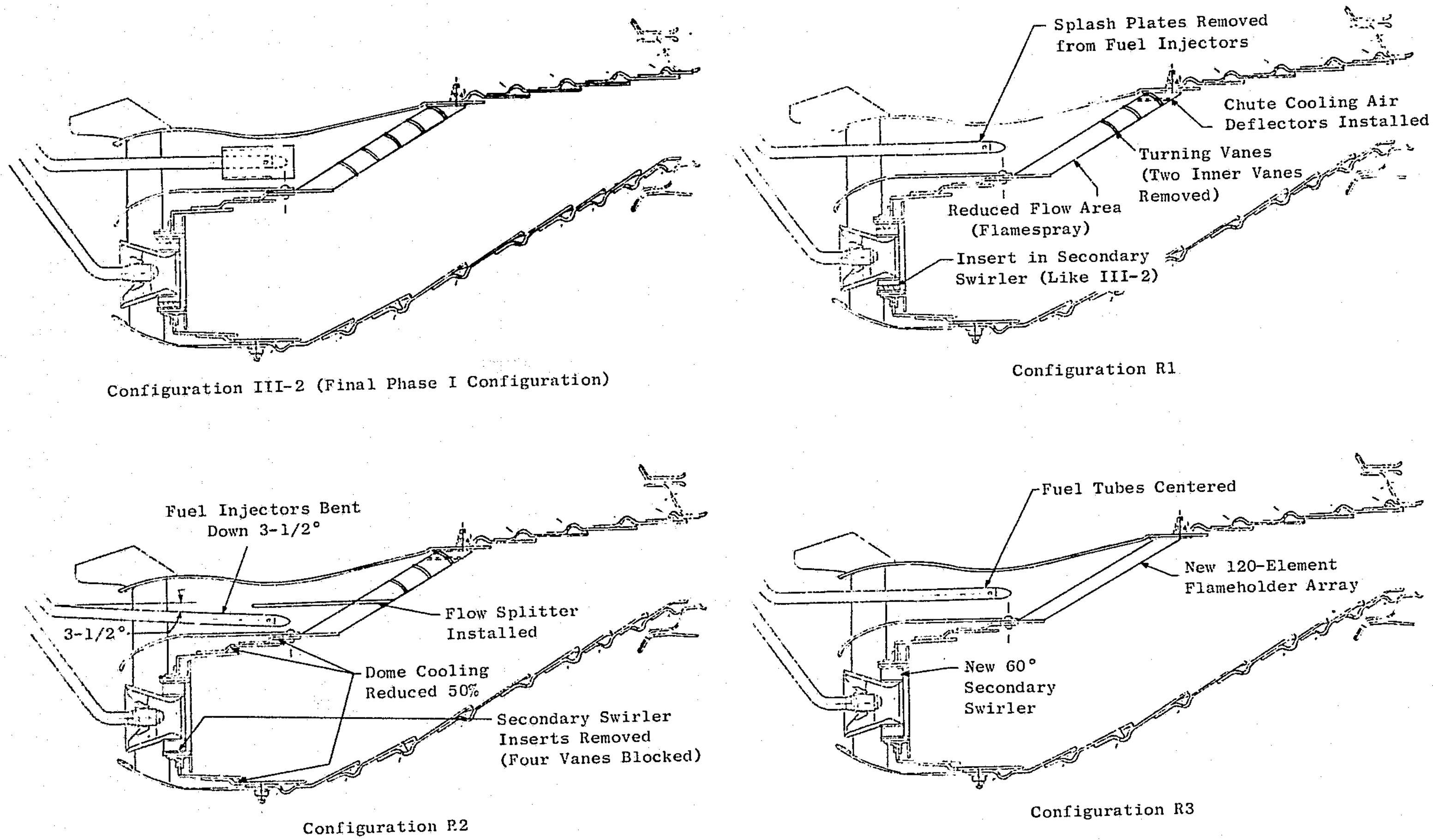


Figure 20. Radial/Axial Staged Combustor Design Parameter Variations, Configurations III-2 - R3.

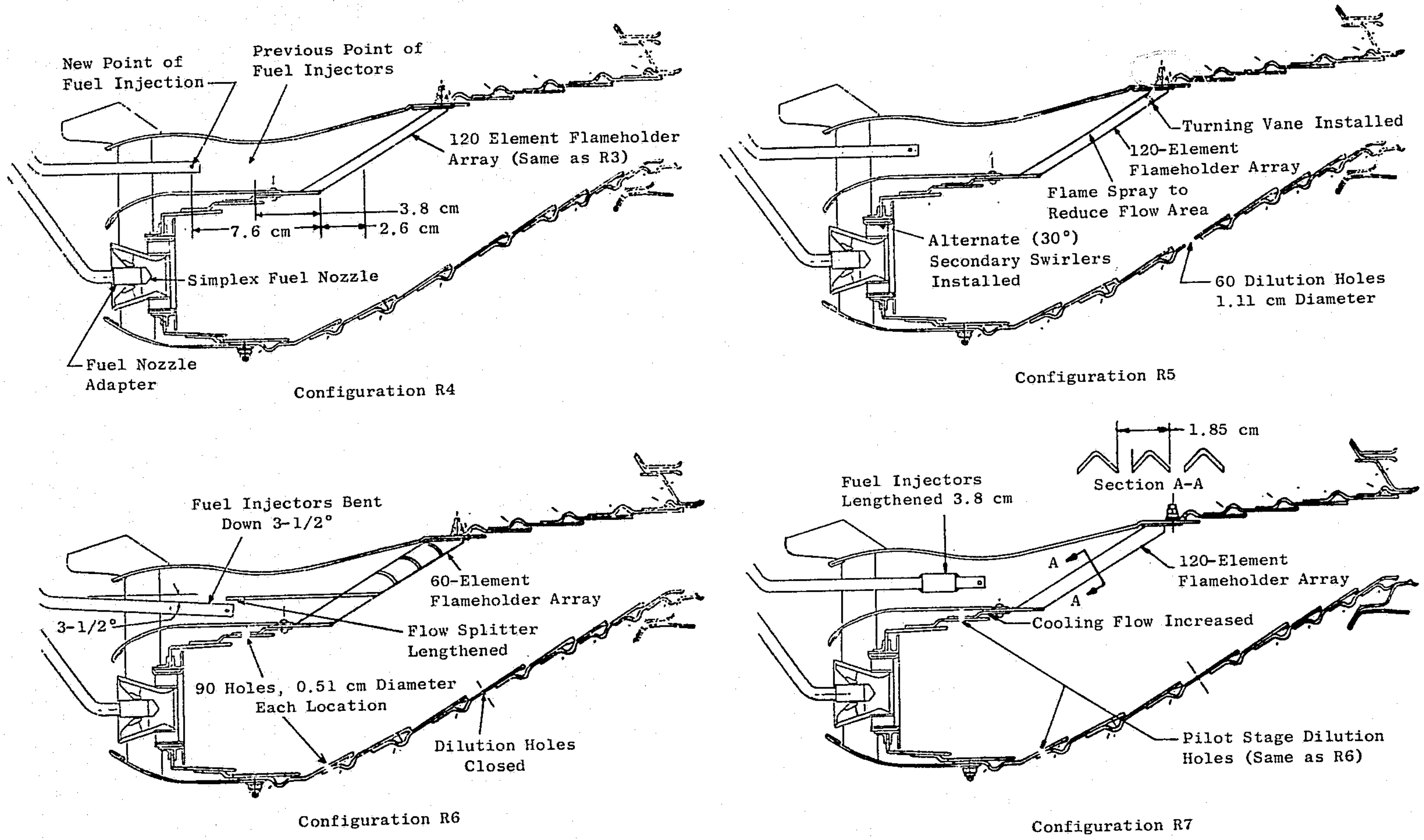


Figure 21. Radial/Axial Staged Combustor Design Parameter Variations, Configurations R4 - R7.

Table XII. Radial/Axial Staged Combustor, Area/Airflow Distributions, Full Annular Test Configurations.

Configurations	R1		R2		R3		R4		R5		R6		R7	
	A_e, cm^2	$\%W_c$	A_e, cm^2	$\%W_c$	A_e, cm^2	$\%W_c$	A_e, cm^2	$\%W_c$	A_e, cm^2	$\%W_c$	A_e, cm^2	$\%W_c$	A_e, cm^2	$\%W_c$
Pilot Cups														
Fuel nozzle shroud	5.2	0.9	5.2	1.0	5.2	0.9	0.6	0.1	0.6	0.1	0.6	0.1	0.6	0.1
Primary swirler	19.4	3.2	19.4	3.6	19.4	3.2	19.4	3.3	19.4	4.0	19.4	3.4	19.4	4.2
Secondary swirler	32.9	5.5	47.7	8.7	47.1	7.9	47.1	7.9	53.5	11.2	53.5	9.4	53.5	11.5
Total	57.5	9.6	72.3	13.3	71.7	12.0	67.1	11.3	73.5	15.3	73.5	12.9	73.5	15.8
Main Stage Flameholders														
Carbureted	383.9	63.7	101.0	18.6	389.7	65.0	389.7	65.5	225.0	46.9	101.0	17.7	219.3	47.2
Uncarbureted	0.0	0.0	231.0	42.5	0.0	0.0	0.0	0.0	0.0	0.0	231.0	40.7	0.0	0.0
Total	383.9	63.8	332.0	61.1	389.7	65.0	389.7	65.5	225.0	46.9	332.0	58.4	219.3	47.2
Dilution														
Pilot stage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.8	4.5	25.8	5.6
Inner liner	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	42.5	8.9	0.0	0.0	0.0	0.0
Total	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	42.5	8.9	25.8	4.5	25.8	5.6
Cooling														
Pilot stage	66.5	11.0	45.2	8.4	45.2	7.5	45.2	7.6	45.2	9.5	45.2	7.9	52.3	11.3
Flameholders	7.7	1.3	7.7	1.4	6.5	1.1	6.5	1.1	7.1	1.5	6.5	1.2	7.7	1.6
Outer liner	33.7	5.6	33.7	6.2	33.7	5.6	33.7	5.7	33.7	7.0	33.7	5.9	33.7	7.3
Inner liner	44.7	7.4	44.7	8.2	44.7	7.5	44.7	7.5	44.7	9.3	44.7	7.8	44.7	9.6
Seal leakage	7.7	1.3	7.7	1.4	7.1	1.3	7.7	1.3	7.7	1.6	7.7	1.4	7.7	1.6
Total	160.3	26.6	139.0	25.6	137.8	23.0	137.8	23.2	138.4	28.9	137.8	24.2	146.1	31.4
Combustor Total	601.7	100.0	543.3	100.0	599.2	100.0	594.6	100.0	479.4	100.0	569.1	100.0	464.7	100.0

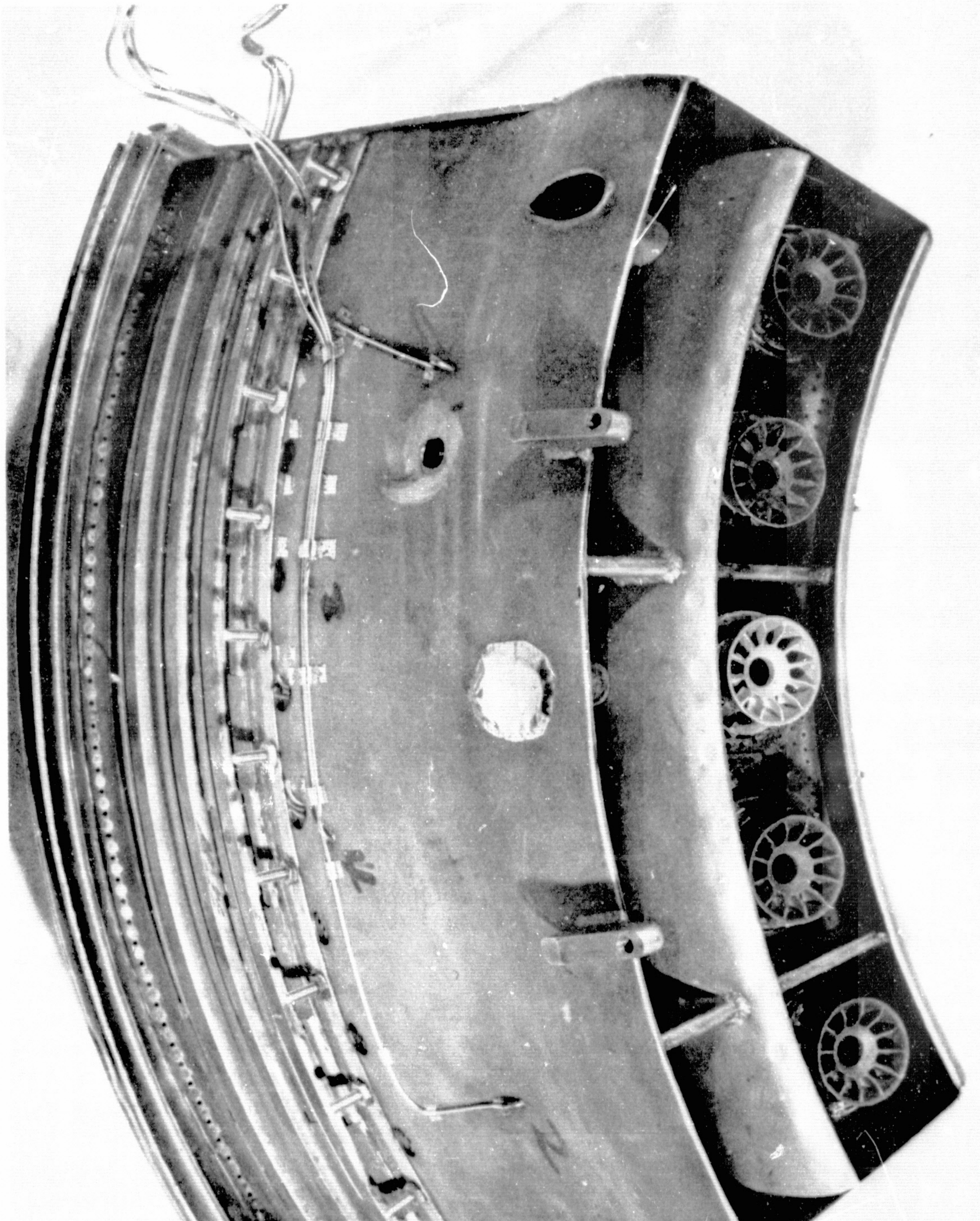


Figure 22. Radial/Axial Staged Sector Combustor Assembly.

Table XIII. Radial/Axial Staged Combustor Altitude Relight Test Configurations, 60° Sector Rig.

Configurations	Intent of Test Sequence
RS1	Baseline test with air blast fuel injectors
RS2	Determine the effect of pressure-atomizing nozzles, increased secondary swirl angle, and increased igniter immersion.
RS2A, RS2B	Determine the effect of reduced secondary swirl angle and alternate igniter location.
RS3	Determine the effect of pilot stage dilution.

In addition, at many test conditions, data were obtained over a range of combustor fuel-air ratios. At some fuel-air ratios the effect of varying the fuel flow splits between combustor stages was also examined.

Test points were usually run in order of increasing combustor inlet temperature for safety considerations and to expedite testing, and data were recorded in two phases. First, the fixed combustor instrumentation was recorded, and then a survey of the combustor exit plane was made, collecting detailed exit temperature and pollutant emission data. The normal test procedure was to obtain exit thermocouple and emission data at 6° intervals around the combustor exit annulus. At test points of particular interest, a high density traverse with 3° spacing was conducted.

Smoke data were extracted from the combustor exit plane with ten probe elements which were manifolded together to provide one average sample. At least three smoke spots were taken at each test condition and the average SAE Smoke Number determined.

A more complete description of the pollutant emissions measurement system and procedures can be found in Appendix B of Reference 6.

Full Annular Ground Start Tests

In addition to elevated pressure tests, the ground start ignition characteristics of three configurations were also evaluated. To determine the sea level ignition characteristics, the combustor was exhausted to the atmosphere allowing visual observation of the ignition attempts. A combustor airflow, within the range of starting airflows of the CF6-50 engine, was set with ambient temperature inlet air. The fuel flow was slowly increased and ignition attempted. The fuel flow was recorded where one cup was lit, where 50% propagation occurred and where 100% propagation occurred. The fuel flow was then decreased and the conditions where one cup was out, where 50% of the cups were out and where lean blowout occurred were recorded. This process was repeated several times until sufficient data repeatability was achieved. A second, third and sometimes, fourth combustor airflow was then set and the entire procedure was repeated. This test procedure is identical to that employed during the ground start testing conducted on the production CF6-50 engine combustor.

Full Annular and 60° Sector Altitude Relight Tests

The altitude relight test procedures for both the full annular and 60° sector rigs consisted of determining combustor ignition and blowout limits over a range of test conditions selected from the CF6-50 engine altitude windmilling map, shown in Figure 23. Most of the tests were conducted with ambient temperature fuel and inlet air. The most promising 60° sector combustor configurations were also evaluated with both cold air and fuel. Ignition attempts were usually made at the engine minimum fuel flow rate

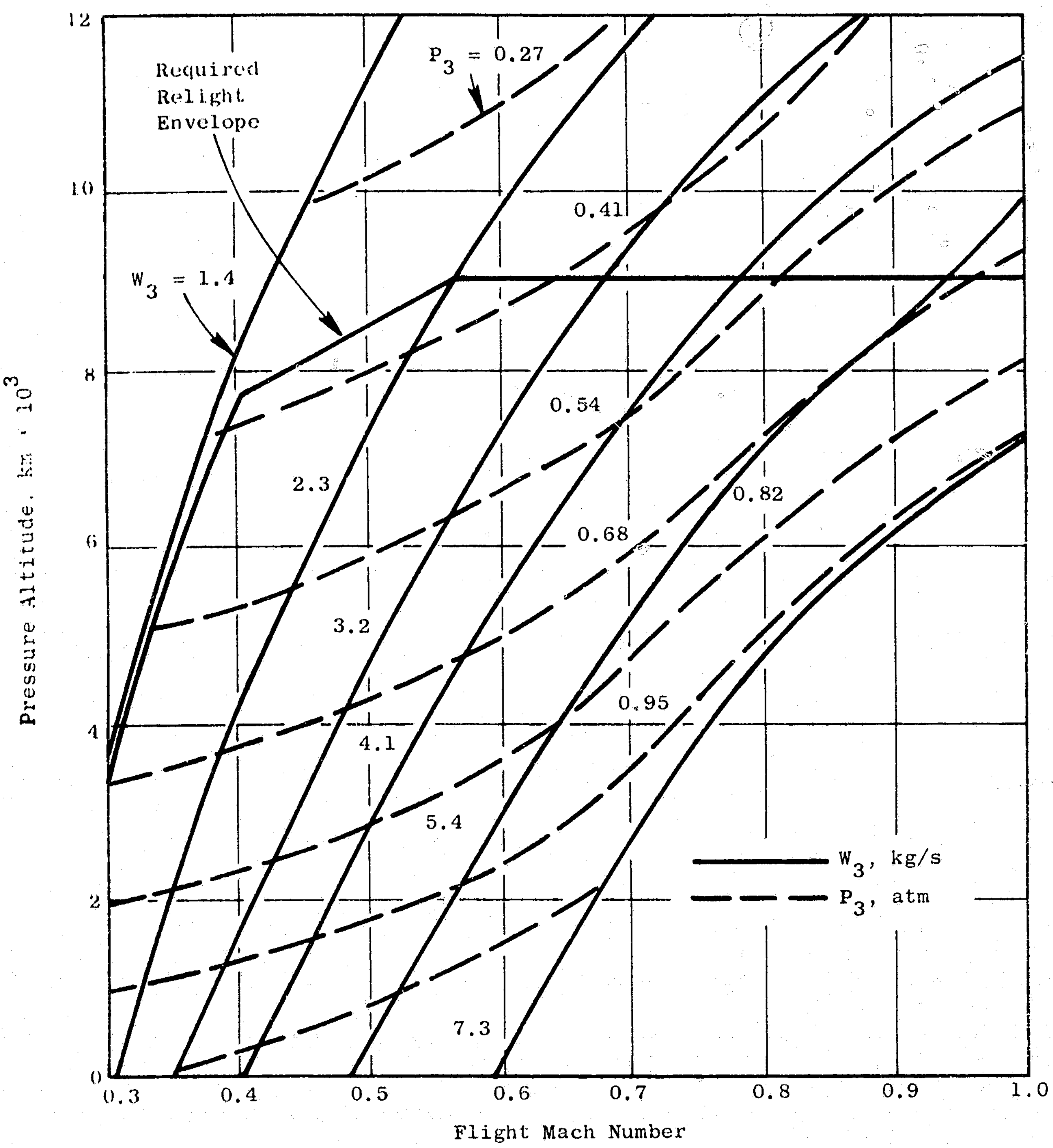


Figure 23. CF6-50 Estimated Windmilling Combustor Conditions.

of 249 kg/hr. When the ignition attempt was unsuccessful, the process was repeated at higher fuel flow rates. When the attempt was successful, pressure blowout and lean blowout limits were measured. The procedure was then repeated at progressively more severe simulated windmilling conditions to map the relight capabilities of each test configuration.

12° Sector Carbon/Flashback Tests

The carboning test procedure consisted of subjecting a fuel injector/air swirler configuration to a simulated combustor duty cycle. At the completion of the standard test cycle, shown in Table XIV, the parts were visually inspected for carbon deposits. The tests lasted 4-1/2 hours and a heavy distillate fuel was used to impose a severe condition upon the fuel nozzle/air swirler configuration. Experience from previous combustor development programs has shown that results obtained from this test adequately represent results obtained from long-time full annular combustor tests using normal kerosene fuel.

For the flashback tests with the Radial/Axial Staged Combustor sector, the sector was instrumented to measure pressure loss, flameholder metal temperatures, and air temperatures in the premixing passage in order to detect upstream burning. Simulated climbout and takeoff operating conditions at two pressure levels, with a range of fuel flow splits between combustor stages, were investigated. The test conditions were:

Combustor dome $\Delta P/P_3$	4.0%	
Inlet pressure	9.5, 16 atm.	12 total test conditions
Inlet temperature	786, 821 K	
Pilot stage fuel-air ratio	0.004, 0.006, 0.008	
Overall fuel-air ratio	0.026	

Each of the 12 combinations of inlet conditions was set with only the pilot stage fueled. The main stage fuel flow was then cycled from zero to maximum then back to zero, while the various temperatures were monitored on strip chart recorders to detect upstream burning.

DATA ANALYSIS PROCEDURES

Combustor Performance Data Processing

A summary of the important combustor operating performance parameters which were measured or calculated in the full annular combustor tests is shown in Table XV. Most of the parameters and equations are self-explanatory, but a few require further clarification:

- By General ELectric convention, reference velocity is based on total inlet airflow, total inlet density and casing cross sectional area at the dome exit. For the CF6-50 flowpath, this reference area is 3,729 cm^2.

Table XIV. Standard Carboning Test Cycle.

- Single Nozzle Rig
- Heavy Distillate Fuel

Test Condition	Combustor Inlet Pressure, atm	Combustor Inlet Temperature, K	Fuel Flow Rate (one nozzle), kg/hr	Combustor Dome Pressure Drop, %	Hold Time, minutes
1	2.14	383	15.3	3.1	30
2	8.30	569	70.8	3.1	30
3	10.95	619	107.5	2.7	30
4	11.70	666	130.6	2.7	30
5	11.97	693	138.3	2.6	30
6	11.70	666	130.6	2.7	30
7	10.95	619	107.5	2.7	30
8	8.30	569	70.8	3.1	30
9	2.14	383	15.3	3.1	30

$\Sigma = 4.5$ hours

- Each combustor exit temperature was computed from the metered fuel-air ratio and average gas sample combustion efficiency (with measured inlet temperature and standard thermodynamic charts). Thermocouple data were used to compute exit temperature profile factors and pattern factors. No radiation or convection corrections were applied to the thermocouple data.

The performance parameters of Table XV, along with the appropriate emission levels, are tabulated in Appendix C for each full annular combustor test and in Appendix D for the 60° sector tests. In Appendix D, the airflows and fuel flows have been converted to "equivalent" annular flow levels by multiplying the sector levels by 6.

Pollution Emission Data Processing

Gaseous pollution data were transmitted directly to an on-line data reduction computer for calculation of the emission concentrations, the emission indices, the combustion efficiency and the fuel-air ratio of the gas sample at each traverse position. Based on the individual gas sample emission index, fuel-air ratio and combustion efficiency values at each traverse location, the overall average emission indices, sample fuel-air ratio and combustion efficiency for the test conditions were determined by mass averaging. These averaged values are presented in tables and figures in this report.

The emission data processing and reduction program, developed in the Phase I Program, was utilized. The equations used were basically those contained in SAE ARP 1256 (Reference 10). CO and CO_2 concentrations were corrected for the removal of water from the sample before its analysis. Aviation kerosene (JP-5 fuel), with a typical value for the fuel hydrogen-to-carbon atom ratio of 1.92 was used throughout these tests. Frequent fuel analyses, obtained throughout the test series, confirmed this value.

Pollution Emissions Correlation

Correlations relating pollutant emission levels to combustor operating conditions were used to:

- Extrapolate data from the reduced pressure test conditions to the full engine operating pressure.
- Extrapolate data to combustor inlet conditions which were not investigated during a test.
- Normalize a range of data to standard test conditions.

The basis for the emissions extrapolation relationships are discussed in detail in Appendix A. The following relationships were used:

Table XV. Summary of Measured and Calculated Combustor Parameters for Full Annular Tests.

Parameter	Symbol	Units	Measured	Calculated	Value Determined From
Inlet Total Pressure	P_{T_3}	atm	X		Average of measurements from 5 immersions on 4 rakes (20 total)
Exit Total Pressure	$P_{T_{3.9}}$	atm	X		Average of measurements from 2 immersions on 5 rakes (10 total)
Total Pressure Loss	$\Delta P_T/P_{T_3}$	%		X	$100\ (P_{T_3} - P_{T_{3.9}})/P_{T_3}$
Total Inlet Airflow	W_3	kg/s	X		ASME orifice
Combustor Bleed Airflow	W_{bleed}	kg/s	X		ASME orifice
Combustor Airflow	W_c	kg/s		X	$W_3 - W_{bleed}$
Reference Velocity	V_R	m/s		X	$W_3/\rho_{T_3} A_R = 0.0248\ W_3\ T_{T_3}/P_{T_3}$
Total Fuel Flow	W_f	kg/hr	X		Turbine flowmeter
Pilot Stage Fuel Flow	W_{f_p}	kg/hr	X		Turbine flowmeter
Main Stage Fuel Flow	W_{f_m}	kg/hr	X		Turbine flowmeter
Overall Metered Fuel-Air Ratio	f	–		X	$W_f/3600\ W_c$
Pilot Stage Fuel-Air Ratio	f_p	–		X	$W_{f_p}/3600\ W_c$
Main Stage Fuel-Air Ratio	f_m	–		X	$W_{f_m}/3600\ W_c$
Inlet Air Humidity	H	g/kg	X		Dew point hygrometer
Inlet Total Temperature	T_{T_3}	K	X		Average of measurements from 2 immersions on 4 rakes (8 total)
Exit Total Temperature	$T_{T_{3.9}}$	K		X	Combustion temperature rise curves, using P_{T_3}, T_{T_3}, f_m, $\eta_{G/S}$
Pattern Factor	PF	–		X	$(T^{*}_{T3.9,\ max.} - T_{T3.9,\ avg})/(T_{T3.9\ avg} - T_{T3})$ – from thermocouples
Profile Factor	Pr F	–		X	$(T^{**}_{T3.9,\ immersion\ average,\ max.} - T_{T3})/(T_{T3.9\ avg} - T_{T3})$ – from thermocouples

*Maximum individual exit temperature measured.

**Maximum of the average exit temperatures calculated at each radial immersion.

$$EI_{NO'_x} = EI_{NO_x} \left(\frac{V_R}{V'_R}\right)^{1.0} \left(\frac{P'_3}{P_3}\right)^{n} \exp\left[\frac{T'_3 - T_3}{169} + \frac{H-6.29}{53.19}\right]$$

Where n = 0.2 for pilot-stage-only data at approach conditions
n = 0.5 otherwise

$$EI'_{CO} = EI_{CO} \left(\frac{P_3}{P'_3}\right)^{n} \quad \text{where } n = 0.2 \left(\frac{100}{EI_{CO}}\right)^{0.7} \text{ for two-stage data}$$

$$= 0.6 \left(\frac{100}{EI_{CO}}\right)^{0.7} \text{ for pilot-stage-only data}$$

$$EI'_{HC} = EI_{HC} \left(\frac{P_3}{P'_3}\right)^{1.0}$$

The primed symbols refer to the extrapolated condition and the unprimed symbols refer to the measured condition. Only pressure corrections were applied to the CO and HC emission levels. Occasionally, the NO_x data were extrapolated to test conditions that differed in pressure, temperature and reference velocity, such as when climbout data were extrapolated to the cruise condition for some configurations.

Data tables and figures of this report utilize the extrapolated "engine levels" for NO_x, CO, HC and combustion efficiency (calculated from extrapolated CO and HC levels) unless otherwise noted.

EPA Parameter Calculation

The extrapolated "engine emission levels" were used to calculate EPA parameter values, from the following equation:

$$EPAP_i = 0.1365\, EI_{i,\ idle} + 0.0912\, EI_{i,\ approach} + 0.1487\, EI_{i,\ climb} + 0.0571\, EI_{i,\ takeoff}$$

where i = CO, HC or NO_x

The derivation of this equation is discussed in detail in Appendix B. Since numerous fueling mode combinations were tested, several EPAPs were calculated for each test configuration.

CHAPTER III

PHASE II EXPERIMENTAL TEST RESULTS

In the Phase II Program, the performance and emission characteristics of the Double Annular Combustor and the Radial/Axial Staged Combustor were improved through an extensive sequence of tests. In developing a final combustor design capable of meeting all performance, durability and emission requirements, a significant degree of iteration was required between the full annular, 60° sector and 12° sector tests. Any design changes which provided reduced idle emission results, for example, required testing in sectors to determine the effect of the design change on relight, performance and carbon formation. Similarly, favorable design changes identified from the sector tests were then subsequently evaluated in the full annular configurations to determine their impact on emissions and performance. As a result, certain compromises and tradeoffs were required in the evaluation of the final design in order to meet all operating requirements to the greatest degree possible.

A total of fourteen Double Annular Combustor configurations and seven Radial/Axial Staged Combustor configurations were evaluated in the full annular tests. More Double Annular Combustor tests were conducted since this concept proved to be the most promising and most readily adaptable to engine installation. A total of 52 configurations were tested in the sector tests. Measurements were also taken as part of the Alternate Fuels Addendum and Noise Addendum.

The large number of configurations and the resulting vast quantity of data precludes a discussion of the results obtained with each configuration. Thus, the following sections present a brief summary of the significant test results obtained with each combustor type. Summaries of the performance and emission results for each full annular and sector configuration can be found in Appendix C and D. The test results obtained under the Noise and Alternate Fuels Addendums are published under separate covers (References 8 and 9).

DOUBLE ANNULAR COMBUSTOR

Phase I Results

During the Phase I tests, the Double Annular Combustor produced significant CO, HC and NO_X reductions, relative to the production CF6-50 combustor, at all operating modes. In particular, at high power conditions, NO_X reductions of almost 50% were obtained with essentially no loss in combustion efficiency. At idle conditions, CO and HC reductions of 50 and 80%, respectively were obtained. The areas of concern with this design at the beginning of Phase II were: (1) the performance and emission levels at intermediate

power operating conditions; (2) the ignition and stability of the main stage due to the presence of the centerbody and the high airflow, high velocity combustion zone; (3) control of the exit temperature profile characteristics; (4) development of suitable altitude relight performance, and (5) carbon-free operation of the pilot stage with no loss in emission performance. In addition, further emission reductions were required at idle and takeoff operating conditions to meet the ECCP goals and 1979 EPA standards.

Exhaust Emission Results

The key emission results for each full annular Double Annular Combustor configuration at standard day idle, approach, climbout and takeoff operating conditions, are summarized in Tables XVI and XVII. Standard day cruise results are summarized in Table XVIII. Generally at each operating condition, except idle, a range of fuel flow splits between stages was investigated to determine the split that produced the lowest emission levels. All of the splits are tabulated in Tables XVI-XVII as well as data from each combustor inlet pressure level tested.

Idle Pollution Results - Several design features were identified during initial tests which significantly reduced the idle emissions from this combustor. The first Phase II pilot stage configuration (D1) was similar to the final Phase I configuration (II-16) except for the incorporation of a longer centerbody. Both the idle CO and HC emission levels, shown in Figure 24, were slightly reduced from Configuration II-16. However, the long centerbody made the cross-fire ignition of the inner dome more difficult and compromised the combustor exit temperature profile. In view of the small emissions improvement and significant performance difficulties introduced, the centerbody was shortened to its original length after configuration D2. A radial-inflow secondary swirler was installed in the pilot stage for D2, but no CO or HC reductions were obtained. The 60° sector altitude relight tests showed that pressure-atomizing fuel nozzles were required in the pilot stage of this combustor to approach the relight requirements. Similar nozzles were installed in the full annular combustor for Configuration D4, along with an axial flow secondary swirler in the pilot stage. The resulting CO and HC levels were somewhat below those of previous configurations, with emission indices of 39 and 6, respectively, at the engine idle fuel-air ratio. Mixing barrel extensions on the pilot stage swirl cups, evaluated in Configuration D5, provided HC levels below the ECCP goals for the first time. At fuel-air ratios below 0.011, the CO levels were also significantly reduced, minimizing at an EI of about 20 at a fuel-air ratio of 0.009. The barrels provided additional mixing length for the fuel-air mixture and helped to keep the mixture away from cold metal surfaces within the combustor. It then remained only to shift the CO characteristic curve obtained with D5 to minimize the CO level at the design fuel-air ratio of 0.011. At fuel-air ratios above 0.009, insufficient oxygen was available in the primary zone of the pilot stage to complete the oxidation of CO. Therefore, additional air was supplied through 120 small-diameter dilution holes installed in the first panel of the outer liner. The use of many small holes instead of fewer, larger holes provided

Table XVI. Double Annular Combustor Emission Results, Configurations D1 - D7.

Conf. No.	Idle					Approach						Climbout						Takeoff					
	Rdg. No.	W_{f_p}/W_{f_t}	EI meas. @ 2.9 atm			Rdg. No.	P_3 Test atm	W_{f_p}/W_{f_t}	EI corr. to 11.7 atm			Rdg. No.	P_3 Test atm	W_{f_p}/W_{f_t}	EI corr. to 25.9 atm			Rdg. No.	P_3 Test atm	W_{f_p}/W_{f_t}	EI corr. to 29.8 atm		
			CO	HC	NO_x				CO	HC	NO_x				CO	HC	NO_x				CO	HC	NO_x
Std. Prod.	-	-	73.0	30.0	2.5	-	-	-	4.3	0	10.0	-	-	-	0.3	0	29.5	-	-	-	0.2	0	35.5
D1	32	1.00	46.5	9.0	3.4	37	3.4	1.00	7.7	0.1	10.6	38	4.8	0.48	6.7	0.3	25.5	49	4.7	0.44	0.6	0.04	29.0
						48	6.9	1.00	4.7	0.5	11.7	39	4.8	0.29	0.6	0.1	15.5	50	4.7	0.27	0.1	0.02	18.3
						45	6.9	0.58	71.8	25.8	6.0	40	4.8	0.20	0.9	0.1	14.4	51	4.7	0.18	0.1	0.02	16.4
						44	6.8	0.30	112.5	20.0	3.6	41	4.8	0.15	2.6	0.1	14.4	52	4.7	0.14	0.6	0.02	14.9
						47	6.9	0	64.0	7.1	4.1												
						55	3.4	0.59(1)	56.9	9.5	7.1												
						46	6.9	0.58(1)	52.8	14.8	6.3												
						56	3.4	0.44(1)	60.8	10.5	4.8												
						57	3.4	0.31(1)	75.0	14.5	3.7												
						58	3.4	0(1)	58.1	35.2	2.1												
D2	94	1.00	44.9	9.8	3.4	97	3.4	1.00	5.3	0.2	10.8	107	4.7	0.47	1.7	0.1	32.5	100	4.7	0.44	0.3	0.3	37.5
						115	6.8	0.58	53.6	12.3	9.7	108	4.7	0.29	0.3	0.1	16.3	99	4.7	0.26	0.1	0.5	18.7
						114	6.8	0.29	98.1	12.3	4.6	109	4.8	0.20	0.9	0.1	13.3	111	6.8	0.27	0.1	0.1	20.4
						116	6.8	0	49.7	6.3	5.1	110	4.8	0.14	3.3	0.1	13.6	101	4.7	0.18	0.4	0.2	17.3
																		112	6.8	0.18	0.2	0.1	17.8
																		102	4.7	0.13	1.0	0.1	18.1
																		113	6.8	0.14	0.8	0.1	18.4
																		103	4.7	0	0.8	0.1	22.5
D3	156	1.00	67.0	37.6	3.0	163	3.4	1.00	16.2	0.3	8.5	181	4.7	0.47	8.4	0.1	29.3	173	4.8	0.44	2.2	0.03	35.9
						168	6.8	1.00	14.9	0.1	9.4	182	4.7	0.28	1.6	0.04	21.1	174	4.7	0.26	0.6	0.02	25.9
												183	4.7	0.19	2.5	0.03	17.9	170	6.8	0.26	0.5	0.1	26.0
												184	4.7	0.14	5.4	0.1	17.7	175	4.7	0.18	1.0	0.02	23.8
																		171	6.8	0.18	0.7	0.1	24.1
																		176	4.7	0.13	2.5	0.1	24.0
																		172	6.8	0.13	2.0	0.1	23.8
																		177	4.7	0	4.2	0.1	28.0
D4	230	1.00	39.1	6.2	3.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D5	238	1.00	38.0	2.4	3.7	243	3.4	1.00	13.1	0.04	7.7	254	4.8	0.48	8.0	0.1	27.7	256	8.5	0.28	0.2	0.03	22.6
												253	4.8	0.29	1.5	0	16.9	255	8.5	0.23	0.2	0.02	21.6
												252	4.8	0.19	1.2	0	15.1						
D6	288	1.00	24.7	2.1	3.8	292		1.00	6.4	0.03	9.6	-	-	-	-	-	-	-	-	-	-	-	-
D7	451	1.00	20.7	1.3	-	440	3.4	1.00	3.8	0.1	-	445	4.8	0.29	1.3	0.1	-	448	4.8	0.45	0.8	0.02	-
	474	1.00	24.9	1.3	-							449	4.8	0.26	0.8	0.03	-	472	9.6	0.35	0.2	0	-
	487	1.00	16.7	0.6	-							444	4.8	0.19	1.9	0.04	-	447	4.8	0.27	0.1	0.01	-
																		473	9.6	0.27	0.2	0	-
																		454	9.5	0.25	0.2	0.03	-
																		446	4.8	0.17	0.4	0.02	-
																		471	9.6	0.18	0.3	0	-

(1) Alternate main injectors fueled

Table XVII. Double Annular Combustor Emission Results, Configurations D8 - D14.

Conf. No.	Idle					Approach						Climbout						Takeoff					
	Rdg. No.	W_{f_p}/W_{f_t}	EI CO	EI HC	EI NO_x	Rdg. No.	P_3 Test atm	W_{f_p}/W_{f_t}	EI CO	EI HC	EI NO_x	Rdg. No.	P_3 Test atm	W_{f_p}/W_{f_t}	EI CO	EI HC	EI NO_x	Rdg. No.	P_3 Test atm	W_{f_p}/W_{f_t}	EI CO	EI HC	EI NO_x
			meas. @ 2.9 atm						corr. to 11.7 atm						corr. to 25.9 atm						corr. to 29.8 atm		
Std. Prod.	-	-	73.0	30.0	2.5	-	-	-	4.3	0	10.0	-	-	-	0.3	0	29.5	-	-	-	0.2	0	35.5
D8	490	1.00	24.3	1.9	3.1	536	3.4	1.00	2.5	0.1	8.4	540	4.8	0.38	0.8	0.1	20.4	544	4.8	0.35	0.1	0.01	24.9
						539	6.8	0.66	60.8	21.9	7.2	541	4.8	0.29	0.2	0.02	17.7	547	4.8	0.27	0.1	0.01	21.8
						533	3.4	0.50	85.4	15.1	6.6	542	4.8	0.20	0.3	0.02	15.3	546	4.8	0.18	0.1	0	19.6
						537	6.8	0.51	81.7	21.5	6.1	543	4.8	0.15	0.8	0.02	14.8	545	4.8	0.13	0.2	0.01	19.7
						534	3.4	0.41	99.3	14.6	5.3												
						535	3.4	0.32	115.8	14.9	4.2												
						538	6.8	0.33	108.4	17.8	4.8												
D9	551	1.00	21.2	3.0	3.2	556	3.4	1.00	1.8	0.1	8.4	574	4.8	0.28	0.1	0.01	16.9	578	4.8	0.44	0.2	0	26.5
	579	1.00	19.2	1.6	3.4	5o2	3.4	0.81	52.2	11.0	9.4	573	4.8	0.20	0.3	0.01	14.5	577	4.8	0.26	0.1	0	21.2
						563	3.4	0.65	66.9	15.2	7.8	572	4.8	0.17	0.8	0.01	13.9	576	4.8	0.18	0.1	0	19.1
						564	3.4	0.51	88.4	16.2	6.3							575	4.8	0.13	0.3	0	19.2
						567	3.4	0.80(1)	35.8	6.3	10.1												
						566	3.4	0.65(1)	44.4	6.7	8.7												
						565	3.4	0.51(1)	48.6	7.4	7.0												
D10	585	1.00	17.8	1.4	3.3	598	3.4	1.00	1.8	0.2	9.1	588	4.8	0.38	3.5	0.05	19.2	592	4.8	0.35	0.2	0	22.9
						608	3.4	0.75(1)	36.3	7.2	9.8	587	4.8	0.30	1.6	0.02	17.4	594	6.8	0.35	0.2	0	23.6
						596	6.8	0.75(1)	29.6	9.2	9.7	586	4.8	0.19	1.8	0.02	14.5	591	4.8	0.27	0.1	0	21.9
						607	3.4	0.51(1)	47.0	8.9	7.1	589	4.8	0.14	3.3	0.01	14.8	590	4.8	0.18	0.2	0	19.9
						595	6.8	0.49(1)	41.6	12.7	6.7							593	4.8	0.14	0.6	0	19.2
						606	3.4	0.29(1)	71.5	15.6	4.5												
D11	611	1.00	20.1	2.5	3.2	614	3.4	1.00	1.6	0.04	8.7	627	4.8	0.39	0.2	0.01	20.1	634	4.8	0.36	0.04	0	25.0
						620	3.4	0.81	48.3	8.8	8.9	626	4.8	0.29	0.1	0.01	18.2	633	4.8	0.27	0.03	0	23.4
						621	3.4	0.51	81.5	13.2	5.4	625	4.8	0.20	0.1	0.01	15.6	632	4.8	0.18	0.05	0	20.7
						622	3.4	0.23	114.2	10.4	3.1	624	4.8	0.15	0.2	0.01	15.1	631	4.8	0.16	0.1	0	20.4
						635	6.8	0.25	104.1	12.3	4.3							630	4.8	0.14	0.1	0.01	19.7
						623	3.4	0	69.5	4.1	4.1												
						619	3.4	0.80(2)	30.8	4.1	10.8												
						637	6.8	0.79(2)	29.0	6.2	10.3												
						618	3.4	0.50(2)	11.5	0.7	8.6												
						636	6.8	0.50(2)	10.8	1.1	7.7												
						617	3.4	0.23(2)	36.9	3.7	5.9												
D12	642	1.00(3)	24.5	7.3	3.3	676	3.4	1.00	3.4	0.1	9.0	680	4.8	0.38	0.7	0.04	21.8	689	4.8	0.35	0.05	0	24.9
	673	1.00	22.0	2.8	3.1	685	6.8	0.79(2)	32.8	8.0	10.0	679	4.8	0.29	0.2	0.03	17.4	688	4.8	0.26	0.05	0.01	22.5
						684	6.8	0.65(2)	30.1	3.8	8.8	678	4.8	0.19	0.2	0.04	14.8	687	4.8	0.18	0.1	0.02	19.6
						683	6.8	0.51(2)	15.1	1.5	7.8	677	4.8	0.15	0.8	0.04	14.6	690	4.8	0.15	0.1	0.01	20.1
						682	6.7	0.40(2)	10.8	1.4	7.0	681	4.8	0.12	1.4	0.04	15.8	686	4.8	0.14	0.2	0.06	19.9
D13	698	1.00	19.0	2.0	3.3	712	3.4	1.00	3.1	0.03	8.5	745	4.7	0.38	0.8	0.01	17.2	750	2.7	0.27	0.1	0	19.4
						704	6.8	0.61(2)	22.0	2.5	8.0	744	4.7	0.29	0.2	0	14.8	746	4.7	0.27	0.1	0	20.0
						703	6.8	0.43(2)	11.5	2.4	6.2	743	4.7	0.19	0.4	0	13.1	701	6.8	0.26	0.1	0.01	20.4
						702	6.8	0.21(2)	39.8	7.5	6.0	742	4.7	0.14	2.1	0.02	13.7	725	9.5	0.26	0.1	0.01	19.1
																		747	4.7	0.20	0.1	0	18.0
																		724	9.5	0.19	0.1	0.01	18.3
																		748	4.7	0.16	0.2	0	19.1
																		723	9.5	0.15	0.2	0.01	18.3
																		749	4.8	0.11	1.0	0	18.7
																		699	9.5	0.11	0.5	0.1	16.8
D14	769	1.00	26.4	3.1	2.6	782	3.4	1.00	3.4	0.2	7.7	777	9.5	0.29	0.3	0.01	19.2	796	9.5	0.27	0.2	0.03	22.9
	788	1.00	28.2	3.7	3.0	799	6.8	0.65	62.3	22.9	7.6	776	9.5	0.19	0.4	0.01	17.6	795	9.5	0.18	0.2	0.03	21.6
	837	1.00(3)	48.4	18.8	3.2	798	6.8	0.44	77.9	16.6	6.5	775	9.5	0.14	0.7	0.01	17.0	794	9.5	0.13	0.5	0.05	21.5
						797	6.8	0.22	90.8	12.8	4.3	778	9.5	0.12	1.4	0.03	17.1	793	9.5	0.09	1.3	0.1	21.8
						831	3.4	1.00(3)	7.1	0.1	8.3												
						830	5.1	1.00(3)	5.5	0.03	8.7												

(1) Alternate main injectors fueled
(2) 180° sector main injectors fueled
(3) Engine prototype pilot stage fuel nozzles

Table XVIII. Standard Day Cruise Emission Results.

Data Corrected to Engine Combustor Conditions

P_{T_3} = 11.4 atm V_R = 24.4 m/s
T_{T_3} = 733 K f = 0.0210

Configuration Number	Reading Number	Test Pressure atm	Pilot Fuel Fraction W_{f_p}/W_{f_t}	Corrected Emission Index, g/kg fuel CO	HC	NO_x	Notes
Std. Prod.	-	-	-	0.7	0.3	16.4	
R1	10	4.8	0.33	39.9	2.4	11.6	1
	9	4.8	0.28	83.8	6.7	8.4	1
	8	4.8	0.23	104.7	14.1	5.6	1
R2	80	4.8	1.00	6.0	0.1	10.9	
	76	4.7	0.35	18.8	0.7	12.2	
	83	4.8	0.34	23.3	0.4	11.0	1
	75	4.7	0.29	23.2	1.3	8.4	
	74	4.8	0.23	28.5	2.5	7.5	
	84	4.6	0.23	36.8	1.9	7.2	1
	79	4.8	0.35	21.5	1.1	10.0	2
	81	4.7	0.34	25.7	0.7	11.7	1,2
	78	4.8	0.28	24.6	1.6	7.9	2
	82	4.8	0.23	36.8	1.9	7.3	1,2
	77	4.8	0.23	29.3	2.5	6.8	2
R3	139	4.7	0.33	41.6	3.1	10.5	1
	151	9.5	0.32	49.2	3.1	9.9	1
	138	4.7	0.23	87.7	19.6	5.9	1
	150	9.5	0.23	80.3	14.6	6.1	1
	137	4.7	0.18	118.0	61.1	4.1	1
	149	9.5	0.18	114.3	52.3	4.3	1
	140	4.8	0.33	38.7	2.1	12.9	1,2
	141	4.7	0.18	67.8	11.6	7.6	1,2
R4	200	4.8	0.45	76.7	5.2	11.4	1
	194	4.8	0.37	64.9	6.9	10.2	
	195	4.8	0.33	72.5	13.1	8.2	
	199	4.8	0.32	88.2	8.3	7.9	1
	196	4.8	0.24	82.9	36.1	4.2	
	198	4.8	0.22	113.8	28.8	4.1	1
	197	4.8	0.18	137.2	82.6	2.5	1
R5	216	4.8	0.40	40.3	2.2	8.0	
	217	4.8	0.33	47.0	4.3	6.1	
	223	4.8	0.33	58.7	4.0	6.0	1
	220	4.8	0.23	84.4	18.2	3.3	1
	218	4.7	0.22	72.6	30.0	3.1	
	219	4.7	0.19	123.0	79.5	2.4	1
R6	268	4.9	0.38	27.4	0.1	8.4	
	269	4.8	0.35	27.6	0.9	7.9	
	271	4.8	0.33	24.0	2.7	6.9	1
	270	4.8	0.24	58.5	12.5	5.1	
R7	394	4.7	0.37	58.3	12.7	4.4	
	398	4.7	0.32	71.5	11.4	3.6	1
	395	4.7	0.23	62.5	66.8	2.8	
	397	4.7	0.23	128.9	87.2	1.5	1
	396	4.7	0.18	97.4	168.7	0.8	1
D1	38	4.8	0.48	23.5	1.9	12.9	1
	39	4.8	0.29	4.9	0.7	7.8	1
	40	4.8	0.20	6.4	0.4	7.3	1
	41	4.8	0.15	12.7	0.4	7.3	1
D2	120	4.7	0.60	18.8	0.6	19.5	
	107	4.7	0.47	10.9	0.4	16.4	1
	119	4.7	0.46	10.6	0.4	15.2	
	118	4.7	0.31	4.2	0.4	8.8	
	108	4.7	0.29	3.5	0.3	8.2	1
	109	4.8	0.20	7.2	0.3	6.7	1
	117	4.7	0.16	18.4	0.6	6.7	
	110	4.8	0.14	15.9	0.4	6.9	1
D3	181	4.7	0.47	29.8	0.8	14.8	1
	182	4.7	0.28	9.5	0.2	10.7	1
	183	4.7	0.19	13.1	0.2	9.0	1
	184	4.7	0.14	21.7	0.6	8.9	1
D5	254	4.8	0.48	29.1	0.5	14.0	1
	253	4.8	0.29	9.0	0	8.5	1
	252	4.8	0.19	8.4	0	7.6	1
D8	540	4.8	0.38	5.4	0.3	10.3	1
	541	4.8	0.29	2.7	0.1	9.0	1
	542	4.8	0.20	3.1	0.1	7.7	1
	543	4.8	0.15	5.6	0.1	7.5	1
D9	570	4.8	0.29	5.6	0.1	8.8	
	574	4.8	0.28	2.4	0.03	8.5	1
	569	4.8	0.20	6.6	0.1	8.2	
	573	4.8	0.20	4.1	0.03	7.3	1
	572	4.8	0.17	6.3	0.2	7.0	1
	568	4.8	0.15	10.3	0.1	7.5	1
D10	588	4.8	0.38	15.9	0.3	9.7	1
	587	4.8	0.30	9.3	0.1	8.8	1
	586	4.8	0.19	10.5	0.1	7.3	1
	589	4.8	0.14	15.7	0.1	7.5	1
D11	627	4.8	0.39	3.3	0.1	10.1	1
	626	4.8	0.29	1.3	0.04	9.2	1
	625	4.8	0.20	1.6	0.1	7.9	1
	624	4.8	0.15	3.1	0.1	7.6	1
D12	680	4.8	0.38	5.5	0.2	11.0	1
	679	4.8	0.29	2.5	0.2	8.8	1
	678	4.8	0.19	3.1	0.2	7.4	1
	677	4.8	0.15	6.1	0.2	7.3	1
	681	4.8	0.12	8.8	0.2	8.0	1
D13	745	4.7	0.38	6.3	0.1	8.7	1
	744	4.7	0.29	3.0	0.03	7.5	1
	743	4.7	0.19	5.8	0.03	6.6	1
	742	4.7	0.14	10.9	0.1	6.9	1
D14	805	4.8	0.39	6.9	0.2	11.2	
	804	4.8	0.29	4.6	0.1	10.1	
	777	9.5	0.29	3.2	0.03	9.7	1
	780	4.8	0.20	5.2	0.1	5.7	
	776	9.5	0.19	4.1	0.03	8.9	1
	779	4.8	0.15	8.8	0.2	8.6	
	775	9.5	0.14	6.4	0.1	8.6	1
	778	9.5	0.12	9.4	0.3	8.6	1

Notes:

(1) Extrapolated from Climbout Test Points.
(2) Alternate Main Injectors Fueled.

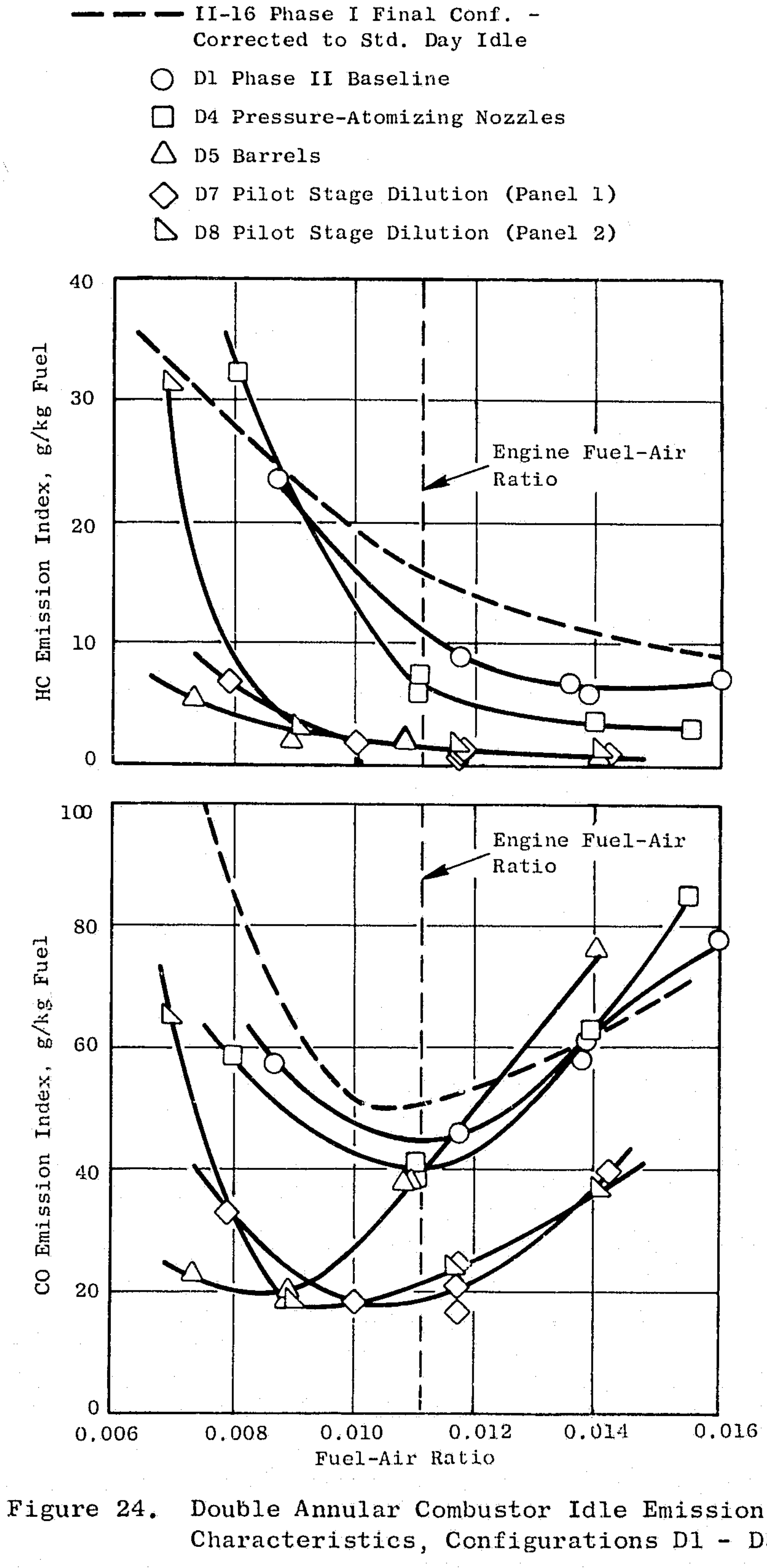


Figure 24. Double Annular Combustor Idle Emission Characteristics, Configurations D1 - D8.

the air more uniformly to the combustion zone and avoided quenching of the CO consumption reactions. The quantity of this dilution airflow was increased in two steps in Configurations D6 and D7. With a total of about 4.7% of the combustor airflow (D7), CO levels minimized very near the design fuel-air ratio as shown in Figure 24. Both CO and HC levels below the ECCP goals were recorded.

The incorporation of the pressure-atomizing fuel nozzle, barrel and outer liner dilution airflow into the pilot stage provided idle emission levels below the ECCP goals and below the levels required for compliance with the 1979 standards. During the subsequent tests, the main emphasis was placed on maintaining these low idle emission levels while introducing the design changes identified from the sector tests to allow the pilot stage to meet the altitude relight requirements and to operate free of harmful carbon deposits. The outer liner dilution holes were shifted from the first to the second panel in Configuration D8. This improved the relight characteristics, with essentially no increase in idle emission levels (Figure 24). No further changes were made to the pilot stage until Configuration D12 when an alternate primary swirler (termed the engine prototype swirler) developed in the 12° sector carbon elimination tests was installed. Again, no significant change in idle emissions resulted, as shown in Figure 25. A pilot stage cooling airflow adjustment and lowered combustion pressure loss introduced in Configuration D14A caused a slight increase in CO and HC levels. The engine combustor design being manufactured for the Phase III engine tests is most like Configuration D12 and comparable idle emission levels are expected during engine tests.

During the tests of Configuration D12 and D14, engine design prototype pilot stage fuel nozzles were also investigated. These configurations were designated D12A and D14B. The use of these prototype nozzles caused a small increase in the HC levels with essentially no change in the CO levels of Configuration D12A. However, in Configuration D14B, a substantial increase in both HC and CO resulted. It appeared from the data that severe quenching of HC and CO occurred in the pilot stage. Subsequent investigations in the 60° sector were conducted to determine the cause. A number of configurations were investigated, including extreme radial positioning of the cups (positioned outward as near the liner metal surface as possible) and severe circumferential misalignment of the fuel nozzles, but the high emission levels of Configuration D14B could not be duplicated. In fact, the design was found to be relatively insensitive to a number of design variables.

Climbout and Takeoff Pollution Results - A number of design features were investigated within the main stage of the Double Annular Combustor to achieve further NO_x reductions at high power and intermediate power operating conditions. The NO_x levels from all configurations were found to be very sensitive to the fuel flow split between burner stages and were minimized when about 80-85% of the fuel was supplied to the main stage at takeoff conditions, as shown in Figure 26. Combustion efficiencies greater then 99.9% were obtained at this flow split, as well as for a wide range of flow

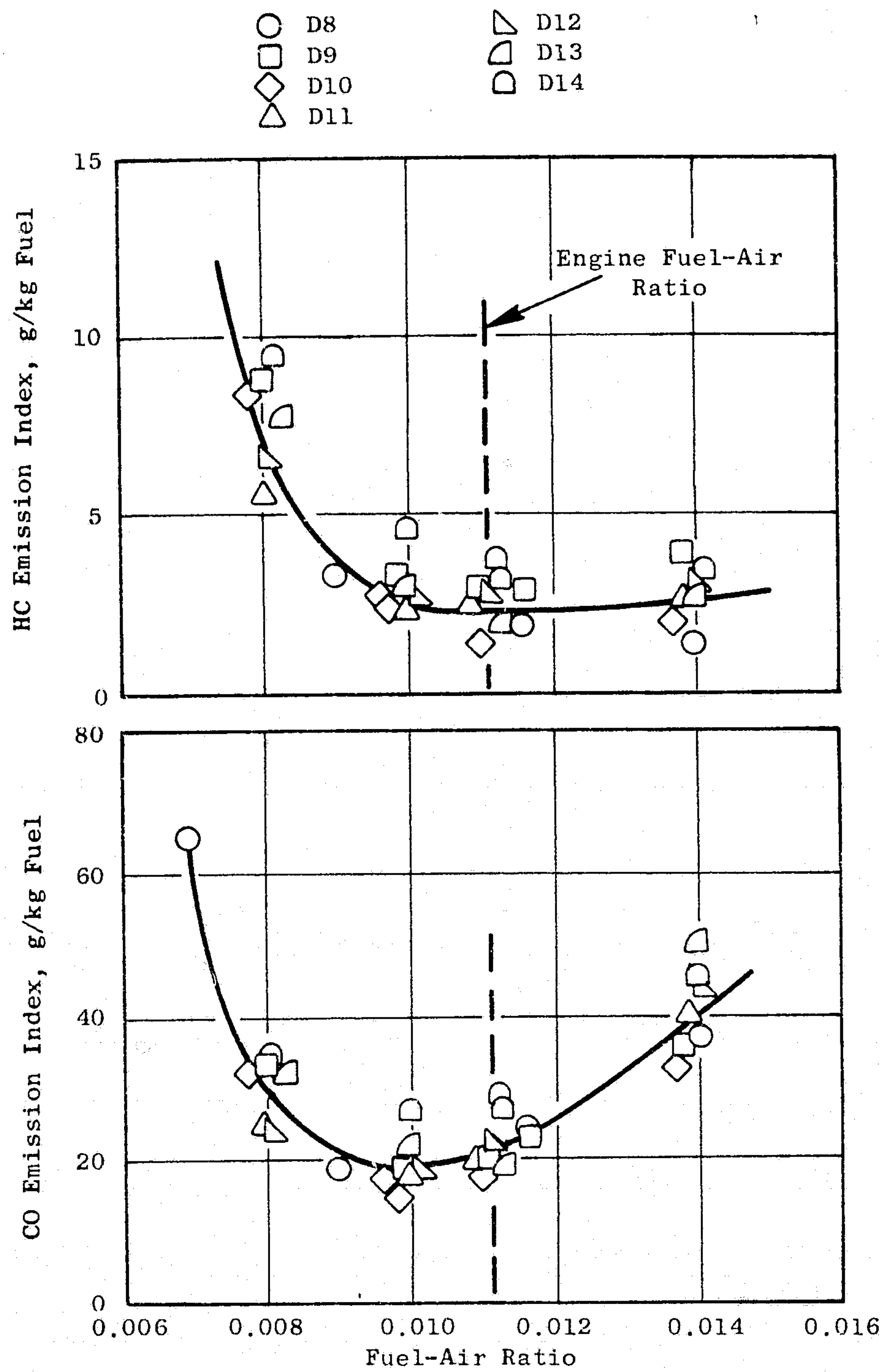


Figure 25. Double Annular Combustor Idle Emission Characteristics, Configurations D8-D14.

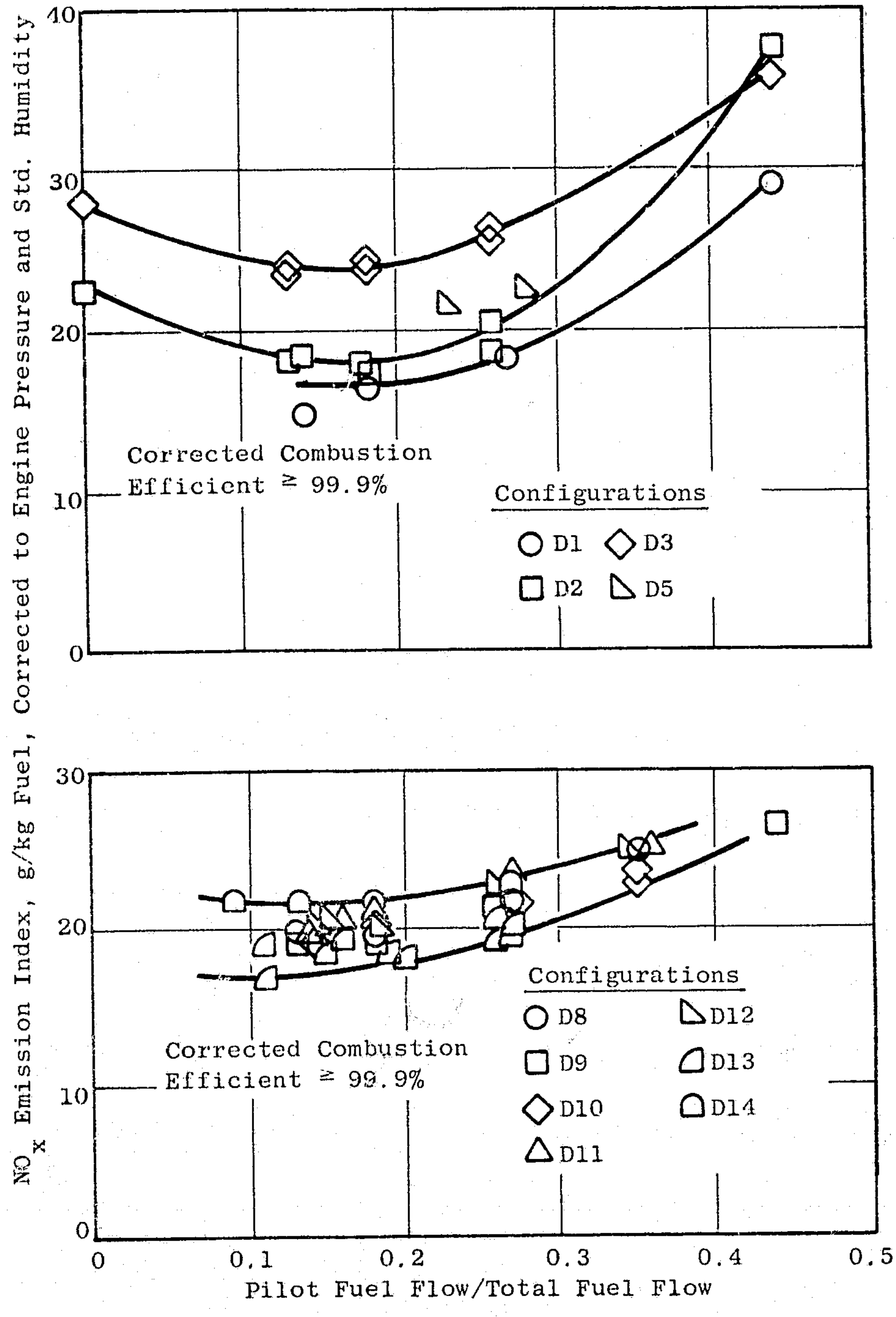


Figure 26. Double Annular Combustor NO_x Emission Characteristics at Takeoff Conditions.

splits, at takeoff and climbout conditions. This combustor can be operated at the fuel flow split which produces the minimum NO_x level, with no loss in efficiency resulting.

The NO_x levels were found to be relatively insensitive to many of the design features investigated. The longer centerbody of Configurations D1 and D2 produced NO_x levels at takeoff and climbout as low as any of the configurations tested. These were EIs of 16.4 - 17.8 at takeoff and 13.3 - 14.4 at climbout. But, the operational difficulties introduced by the longer centerbody outweighed the NO_x reductions obtained. When all of the available main stage airflow was introduced into the swirl cups, and the inner liner dilution holes were closed, the NO_x levels increased sharply (Configuration D3). This was probably due to the lack of mixing between the fuel and air in the swirler prior to combustion. The large quantity of swirler airflow, the short swirler axial length, and the lack of inner dilution jets contributed to this mixing deficiency. With pressure-atomizing fuel nozzles, the mixing in the swirl cups was improved in Configuration D5 with a resulting decrease in NO_x levels to 21.6 at takeoff. Due to main stage ignition and stability problems associated with this high flow swirl cup (discussed in a later paragraph), this cup design was abandoned after Configuration D6. The main stage swirl cups utilized for the Phase I, D1 and D2 configurations were reinstalled in the main stage for Configuration D7.

The remaining tests were aimed at optimizing the dome and liner dilution airflow quantities and locations to obtain the lowest NO_x levels. The elimination of the dome dilution airflow was found to have no effect on NO_x. This is shown in the comparison of Configurations D8 and D10 in Figure 26. Thus dome dilution was eliminated after Configuration D10. Introducing all of the dilution airflow into the first liner panel was found to be more effective than staging the dilution (comparison of Configurations D11 and D12). When the size of the dilution holes was increased to supply more dilution airflow, the NO_x levels were reduced, (Configurations D9 and D13). However, the quantity of dilution airflow introduced in Configurations D9 and D13 is not available in the engine combustor due to higher dome cooling requirements and the need for profile trim air. Configuration D12 is the best simulation of the final engine design and produced NO_x levels of 19.6 and 14.8 at takeoff and climbout, respectively.

The smoke levels of all Double Annular Combustor test configurations at high power operating conditions were extremely low (Appendix C), generally below a smoke number of two. Although a somewhat higher level would be expected at engine pressures, the smoke levels of this combustor should not be a source of concern.

Approach Pollution Results - The approach operating mode, as defined in the EPA landing/takeoff cycle, presents unique problems for all two-stage combustors including the Double Annular design. Because of the relatively low power setting of 30 percent, the combustor inlet conditions and fuel-air ratio are low enough so that only the pilot stage need be fueled. Operating the combustor with only the pilot stage fueled at approach has been found to produce the extremely high combustion efficiencies required to meet the 1979 EPA standards. Results are shown in Figure 27. However, from an engine

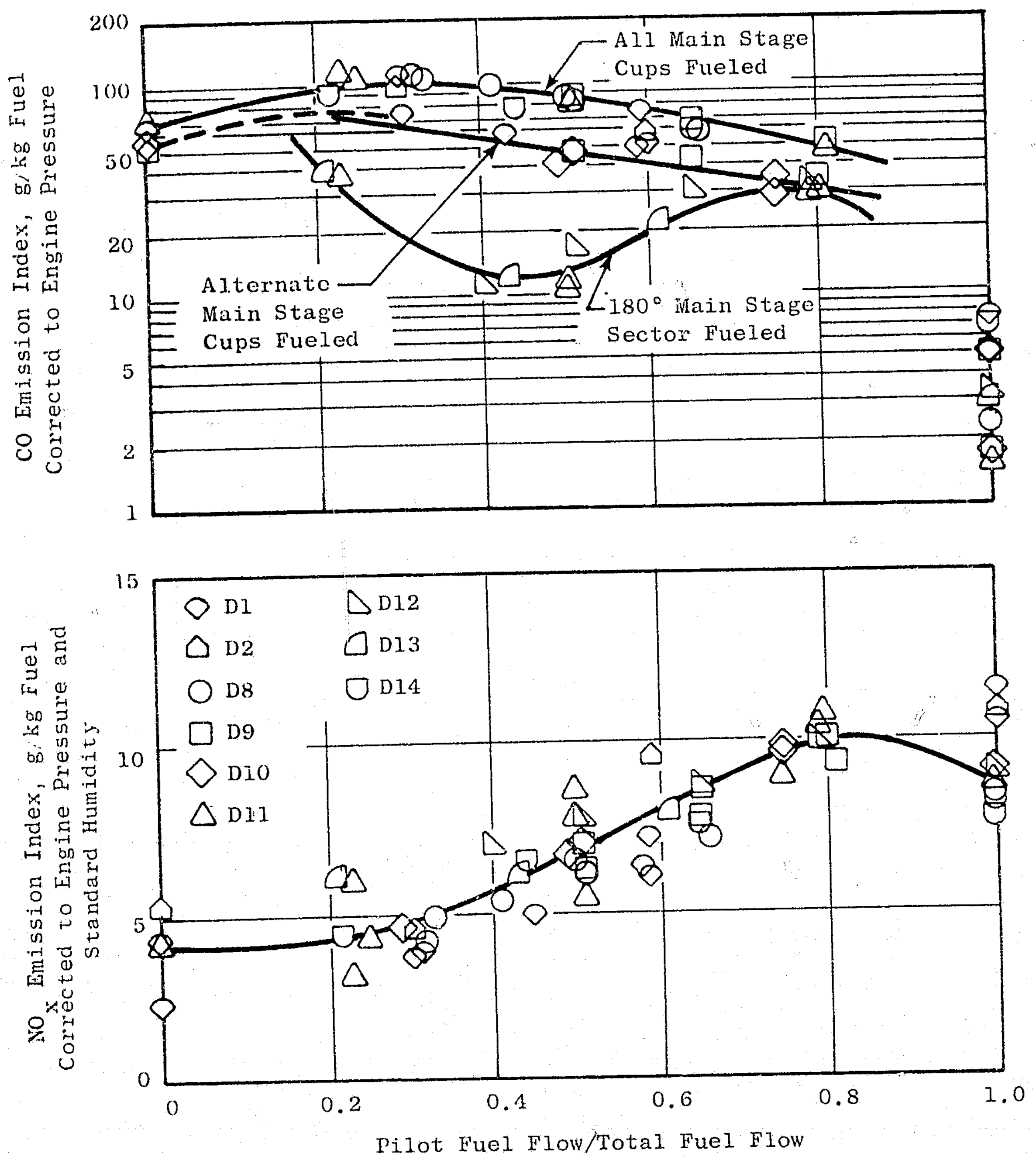


Figure 27. Effect of Fuel Flow Split on Emission Levels of the Double Annular Combustor at Approach Conditions.

operational and flight safety standpoint, it is somewhat undesirable to approach an aircraft landing with only the pilot stage fueled. In case of a wave-off of the landing attempt, the main stage must be rapidly ignited so that the aircraft can have sufficient thrust to climb out of the approach pattern. Thus, it would be desirable for both stages to be fueled at the approach operating condition.

The effects on emissions of scheduling the fuel flow to both combustion stages at approach were investigated in detail. As shown in Figure 27, by supplying fuel to both stages, reduced NO_x levels can be obtained due to the leaner combustion zones. However, poor combustion efficiency and accompanying high CO and HC levels result. If the fuel is supplied to the pilot stage and only alternate main stage cups, somewhat lower CO levels are obtained, but they remain too high for compliance with the EPA standards. But, if fuel is supplied to the pilot stage and to a 180° continuous sector of the main stage, significantly reduced CO levels result. With an equal fuel split between stages, a CO emission index of about 10 can be obtained. This is still somewhat higher than the levels obtained with pilot-stage-only operation, but is reduced 90% from the levels obtained by fueling all of the main stage. Although this staging technique will produce CO and HC emission levels which allow compliance with the CO and HC EPA standards, several operational difficulties would be introduced if it is implemented. A third degree of freedom would be required in the already complex fuel control system, and severe exit temperature gradients, both radial and circumferential, would result. Significant further development would be required to overcome these difficulties. It therefore, appears that pilot-stage-only operation at approach is the only feasible fueling mode at this stage of development to meet the emission standards.

Cruise Pollution Results - The emission levels of the Double Annular Combustor at the cruise condition are summarized in Table XVIII for each Phase II configuration. Some of these data are extrapolated from the climb-out test points, as noted on the table. All configurations produced NO_x levels significantly lower than those of the production CF6-50 combustor, and very high combustion efficiencies. The lowest NO_x levels were obtained with Configuration D13 where an NO_x index of 6.6 was obtained with a combustion efficiency above 99.8%. This represents a 60% NO_x reduction from the standard CF6-50 combustor. Configuration D12, which is the Phase III engine prototype configuration, produced a NO_x level of 7.3, also with an efficiency of over 99.8%.

EPAP Results - The status of each Phase II test configuration relative to the 1979 EPA standards is shown in Table XIX for pilot-stage-only operation at approach. As can be seen, Configurations D7 to D14 all provided CO and HC levels which are below the standards. However, no configuration met the NO_x standard. The lowest NO_x EPA parameter (4.2) was obtained with Configuration D13. This represents a 45% reduction relative to the production CF6-50 combustor. The NO_x levels of the remaining configurations ranged from EPA parameters of 4.4 - 4.8, except for D3 which was higher. Significant further development would be required to meet the NO_x standard with this

Table XIX. Double Annular Combustor EPA Emission Parameters with Pilot-Stage-Only Operation at Approach.

Configuration	Pilot/Total Fuel Split				EPAP (lb/1000 lb thrust-hrs)		
	Idle	App.	Climb	T/O	CO	HC	NO_x
Std. Prod.	–	–	–	–	10.8	4.3	7.7
D1	1.00	1.00	0.20	0.18	6.9	1.3	4.6
D2	1.00	1.00	0.20	0.18	6.8	1.4	4.4
D3	1.00	1.00	0.19	0.13	11.0	5.2	5.3
D4 (1)	–	–	–	–	–	–	–
D5	1.00	1.00	0.19	0.23	6.6	0.3	4.7
D6 (1)	–	–	–	–	–	–	–
D7	1.00	1.00	0.26	0.25	3.3	0.2	– (2)
D8	1.00	1.00	0.15	0.18	3.7	0.3	4.5
D9	1.00	1.00	0.17	0.18	3.1	0.3	4.4
D10	1.00	1.00	0.19	0.14	2.9	0.2	4.5
D11	1.00	1.00	0.15	0.14	2.9	0.4	4.6
D12B	1.00	1.00	0.15	0.18	3.4	0.4	4.5
D13	1.00	1.00	0.19	0.13	3.0	0.3	4.2
D14A	1.00	1.00	0.14	0.13	4.2	0.5	4.8

(1) Incomplete test

(2) NO_x data suspect

combustor. The EPA parameters resulting from staging the fuel at approach conditions are summarized in Table XX. The differences in the EPA parameters for each configuration between Tables XIX and XX are due only to the contributions of the approach condition to the overall EPA parameter. As shown, several configurations would meet the CO and HC standards with sector burning at approach. Other configurations might have, but that mode was not investigated in all tests. The lowest NO_x EPA parameter was obtained with Configuration D13 with sector staging at approach, where an EPA parameter of 4.0 was obtained. This combination also produced CO and HC EPA parameters below the standards.

Combustor Performance Results

The key performance parameters for all full annular and sector configurations tested are tabulated in the data summary tables in Appendix C and D. In addition to the development of acceptable altitude relight performance, elimination of harmful carbon formation and the attainment of satisfactory exit temperature profiles, two other major performance areas of concern were uncovered and resolved during Phase II. These were acoustic resonance from both combustor stages, and serious deficiencies with main stage cross-fire and combustion stability.

Altitude Relight Results - The first Double Annular Combustor configuration evaluated during Phase II was deficient in altitude relight capability, as shown in Figure 28. Fuel flows approximately twice as high as desired (249 kg/hr) were required for ignition at the high altitude windmilling conditions. This was largely due to the lack of adequate combustor pressure drop to sufficiently atomize the fuel droplets at windmilling conditions with low pressure drop, air blast fuel injectors. When pressure-atomizing nozzles were installed in the pilot stage, with essentially no change in swirl cup configuration, significantly reduced fuel flows were required to ignite the combustor. Fuel flows above the desired 249 kg/hr were required only at the high flight Mach number conditions.

The addition of dilution air to the outer liner, required for CO reduction, was found to adversely affect the relight capabilities (Figure 28). But, as shown, when these holes were moved to the second panel downstream of the igniter location, the excellent relight characteristics were restored. The introduction of the pilot stage primary swirler developed in the carbon elimination tests did not affect the relight performance. The results obtained with the sector and full annular combustors configured with prototype pilot stage swirlers are compared in Figure 29. As shown, ignition was obtained over the entire required altitude windmilling map at the CF6-50 engine minimum fuel flow of 249 kg/hr in both the sector and the annular tests.

Ground Start Results - The sea level ignition and subidle temperature rise characteristics of the final design configuration are shown in Figure 30. As shown, subidle temperature rise characteristics essentally equivalent to those of the production CF6-50 combustor were obtained over a wide

Table XX. Double Annular Combustor EPA Emission Parameters with Two-Stage Operation at Approach.

Configuration	Pilot/Total Fuel Split				Approach Fueling Mode*	EPA Parameter lb/1000 lb Thrust-Hrs.		
	Idle	App.	Climb	T/O		CO	HC	NO_x
Std. Prod.	-	-	-	-	-	10.8	4.3	7.7
D1	1.00	0.58	0.20	0.18	1	13.0	3.6	4.1
	1.00	0.30	0.20	0.18	1	16.7	3.1	3.9
	1.00	0	0.20	0.18	1	12.3	1.9	3.9
	1.00	0.59	0.20	0.18	2	11.7	2.1	4.2
	1.00	0.58	0.20	0.18	2	11.3	2.6	4.1
	1.00	0.44	0.20	0.18	2	12.0	2.2	4.0
	1.00	0.31	0.20	0.18	2	13.3	2.6	3.9
	1.00	0	0.20	0.18	2	11.8	4.5	3.7
D2	1.00	0.58	0.20	0.18	1	11.2	2.5	4.3
	1.00	0.29	0.20	0.18	1	15.2	2.5	3.0
	1.00	0	0.20	0.18	1	10.8	1.9	3.9
D8	1.00	0.66	0.15	0.18	1	9.0	2.3	4.4
	1.00	0.50	0.15	0.18	1	11.2	1.6	4.3
	1.00	0.51	0.15	0.18	1	10.9	2.2	4.3
	1.00	0.41	0.15	0.18	1	12.5	1.6	4.2
	1.00	0.32	0.15	0.18	1	14.0	1.6	4.1
	1.00	0.33	0.15	0.18	1	13.3	1.9	4.2
D9	1.00	0.81	0.17	0.18	1	7.6	1.3	4.5
	1.00	0.65	0.17	0.18	1	9.0	1.7	4.3
	1.00	0.51	0.17	0.18	1	10.9	1.8	4.2
	1.00	0.80	0.17	0.18	2	6.1	0.9	4.5
	1.00	0.65	0.17	0.18	2	6.9	0.9	4.4
	1.00	0.51	0.17	0.18	2	7.3	1.0	4.2
D10	1.00	0.75	0.19	0.14	2	6.0	0.9	4.6
	1.00	0.75	0.19	0.14	2	5.4	1.0	4.6
	1.00	0.51	0.19	0.14	2	7.0	1.0	4.4
	1.00	0.49	0.19	0.14	2	6.5	1.4	4.3
	1.00	0.29	0.19	0.14	2	9.3	1.6	4.1
D11	1.00	0.81	0.15	0.14	1	7.2	1.1	4.6
	1.00	0.51	0.15	0.14	1	10.2	1.5	4.3
	1.00	0.23	0.15	0.14	1	13.2	1.3	4.1
	1.00	0.25	0.15	0.14	1	12.3	1.5	4.2
	1.00	0	0.15	0.14	1	9.1	0.7	4.2
	1.00	0.80	0.15	0.14	3	5.6	0.7	4.8
	1.00	0.79	0.15	0.14	3	5.4	0.9	4.7
	1.00	0.50	0.15	0.14	3	3.8	0.4	4.6
	1.00	0.50	0.15	0.14	3	3.8	0.4	4.5
	1.00	0.23	0.15	0.14	3	6.1	0.7	4.3
D12B	1.00	0.79	0.15	0.18	3	6.1	1.1	4.6
	1.00	0.65	0.15	0.18	3	5.9	0.7	4.5
	1.00	0.51	0.15	0.18	3	4.5	0.5	4.4
	1.00	0.40	0.15	0.18	3	4.1	0.5	4.4
D13	1.00	0.61	0.19	0.13	3	4.7	0.5	4.1
	1.00	0.43	0.19	0.13	3	3.7	0.5	4.0
	1.00	0.21	0.19	0.13	3	6.3	1.0	4.0
D14A	1.00	0.65	0.14	0.13	1	9.5	2.6	4.8
	1.00	0.44	0.14	0.13	1	11.0	2.0	4.7
	1.00	0.22	0.14	0.13	1	12.1	1.6	4.5

*Approach Fueling Mode:
1 = All inner cups fueled
2 = Alternate inner cups fueled
3 = 180° sector of inner cups fueled

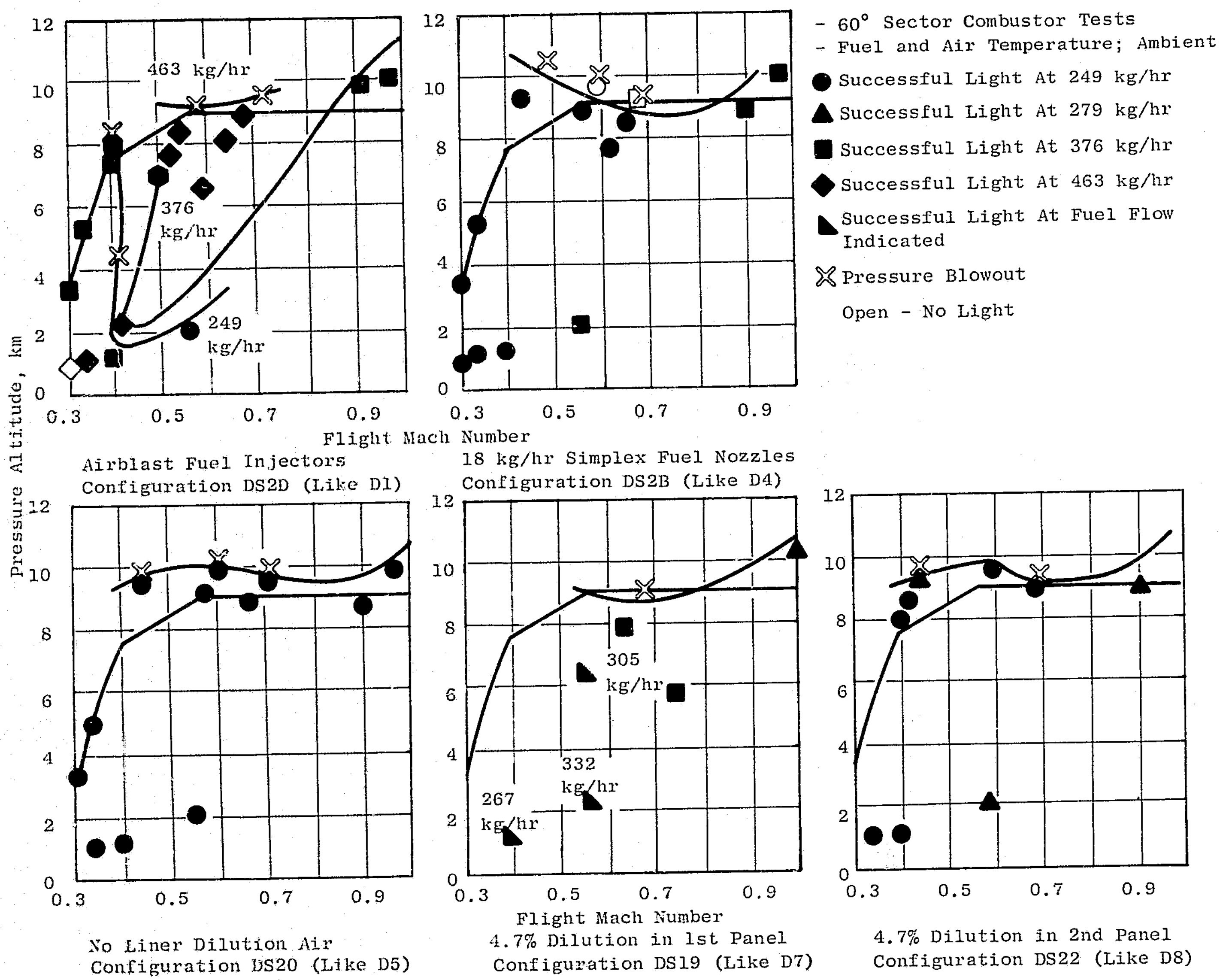


Figure 28. Effect of Design Modifications on Double Annular Combustor Altitude Relight Characteristics.

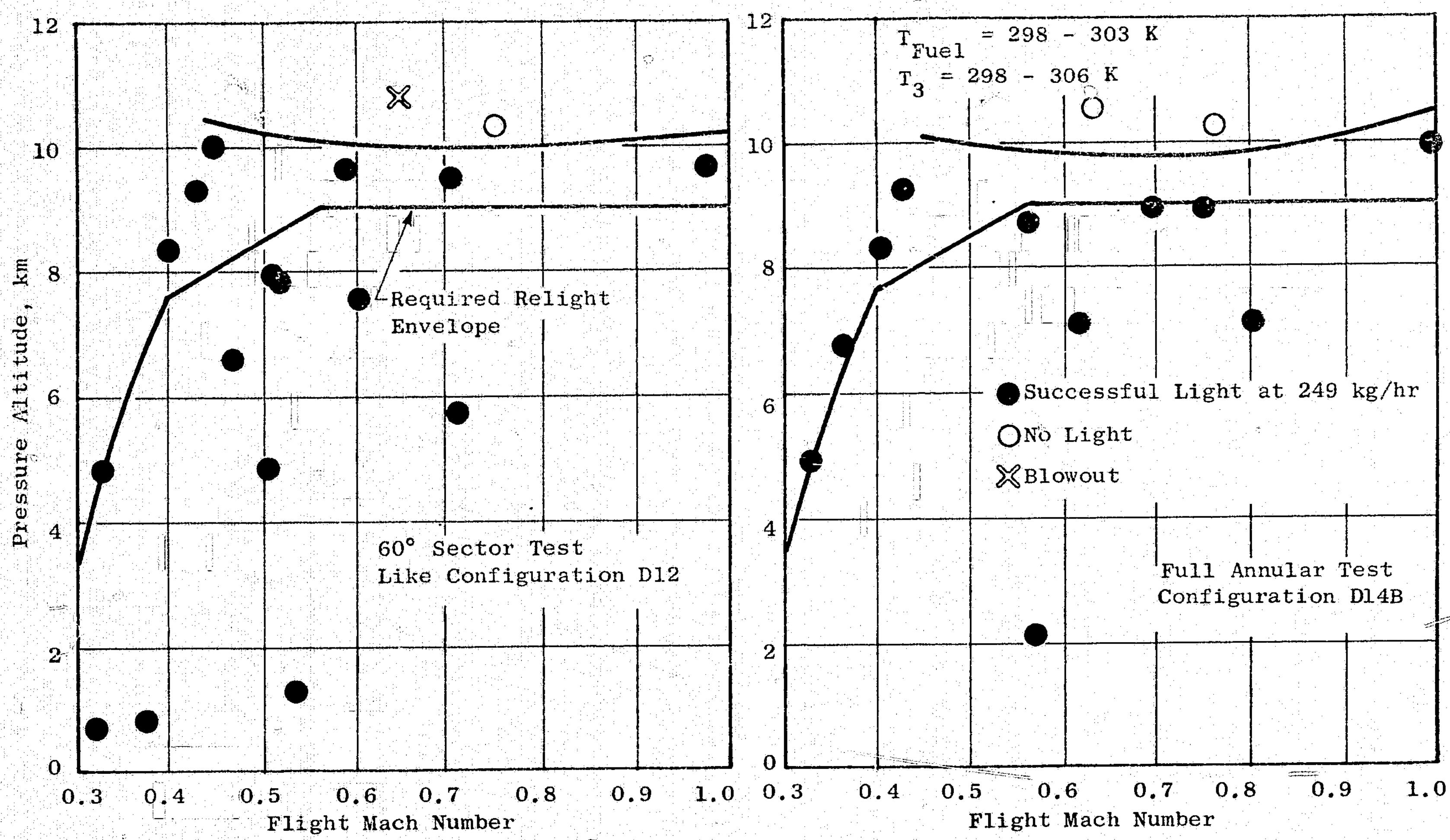


Figure 29. Altitude Relight Characteristics of Final Double Annular Combustor Design Configuration.

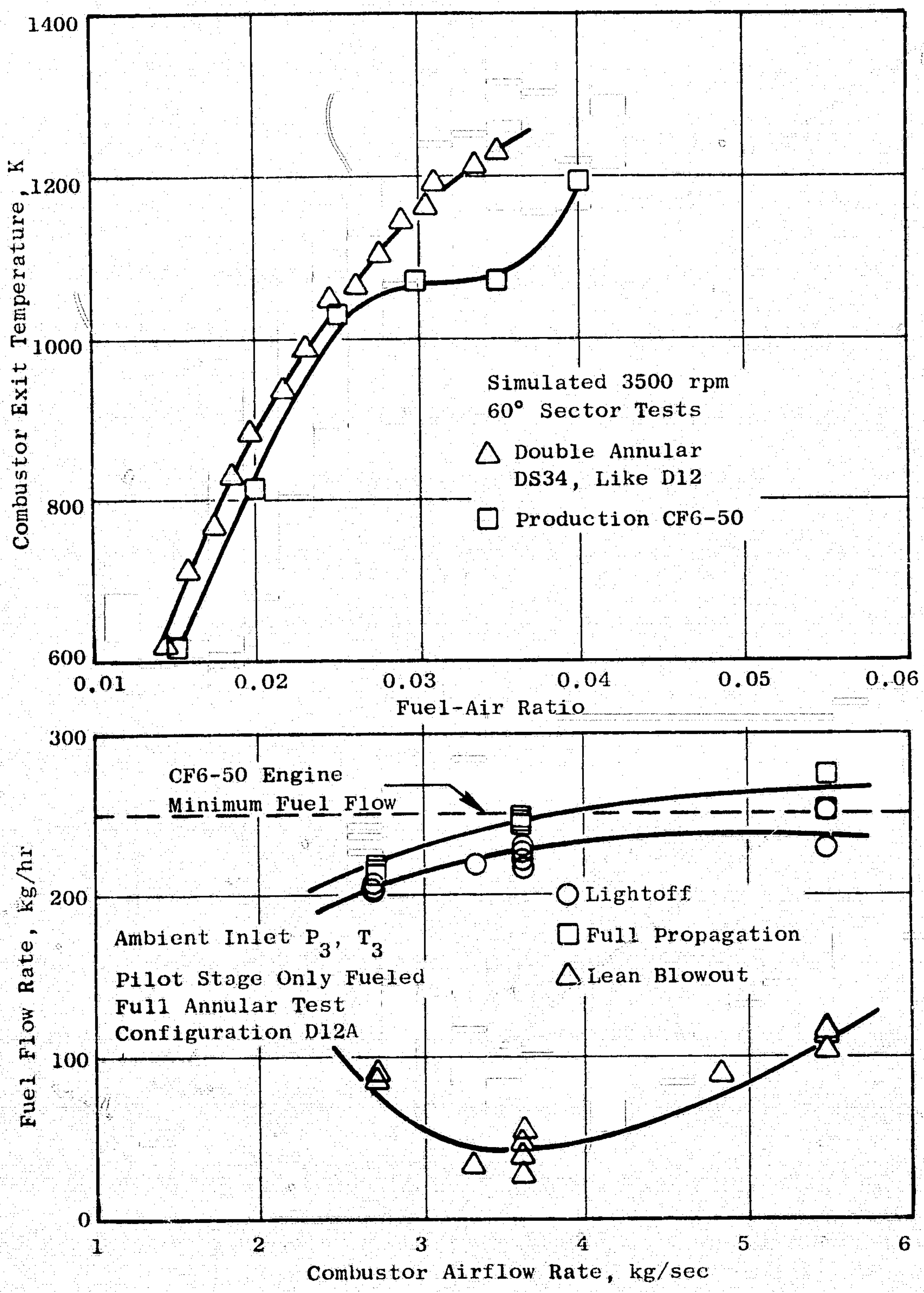


Figure 30. Sea Level Ignition Performance of Final Double Annular Combustor Design Configuration.

range of fuel-air ratios, thereby ensuring good subidle acceleration characteristics with this pilot stage design. In addition, the fuel flows required for engine sea level starting are below or just slightly above the minimum CF6-50 engine scheduled fuel flow over the range of airflows normally encountered during ground start operation.

Carboning Results - Generally, small carbon deposits are permissible downstream of the primary swirler venturi throat since no possible restriction to the airflow would result. However, no carbon deposits upstream of the venturi throat or on the fuel nozzle are acceptable. In the initial test configuration, carbon deposition was present on both the fuel nozzle tips and the primary swirler, near the exit of the swirler vane passages. If allowed to accumulate over a period of time, these deposits might plug the fuel nozzle or the vane passages and produce serious combustor damage.

Eight additional configurations were evaluated in the 12° sector rig and harmful carbon deposits within the swirl cups were eliminated. Results are shown in Figure 31. The important design parameters were found to be the primary swirler-to-venturi throat area ratio, and the distance from the primary swirler vane exit plane to the venturi throat. Based on these parameters, a primary swirler configuration, No. 9 in Figure 31, suitable for use in both combustor stages was developed. This primary swirler design was incorporated into the pilot stage of full annular combustor Configuration D12 and is the design being procured for both stages of the Phase III engine demonstrator combustor.

Acoustic Resonance Results - Acoustic resonance is not tolerable in an engine application because of the danger of cyclic mechanical failure of any combustor or engine hardware whose natural vibratory frequence is near the combustor-generated excitation frequency. No resonance was encountered during the Phase I tests. However, resonance was encountered and successfully overcome in Phase II. Results are summarized in Table XXI.

Nearly pure-tone acoustic resonance was encountered at high power operating conditions in Configuration D5 and at low power operating conditions in Configurations D7-D11. With Configuration D5, a strong 800 Hz signal was observed immediately upon ignition of the main stage. Visual observation of the main stage combustion zone in the 60° sector rig showed the flame to be very unstable. An unstable, unseated flame is capable of producing a resonant frequency due to interactions with the combustor geometry. The unstable flame was apparently caused by the high airflow swirl cup and accompanying lean combustion zone incorporated in the main stage for NO_x reduction. A return to the lower airflow main stage swirl cup previously tested in Phase I and Configurations D1 and D2, eliminated the high power resonance condition in Configuration D7. It was not encountered again in subsequent configurations. However, the addition of outer liner dilution airflow in D7 caused resonance at idle where only the pilot stage is fueled. A predominant 360 Hz resonant frequency was encountered at certain fuel-air ratios. It disappeared at combustor operating conditions above idle. This resonance was eliminated in Configuration D12 with the introduction of the

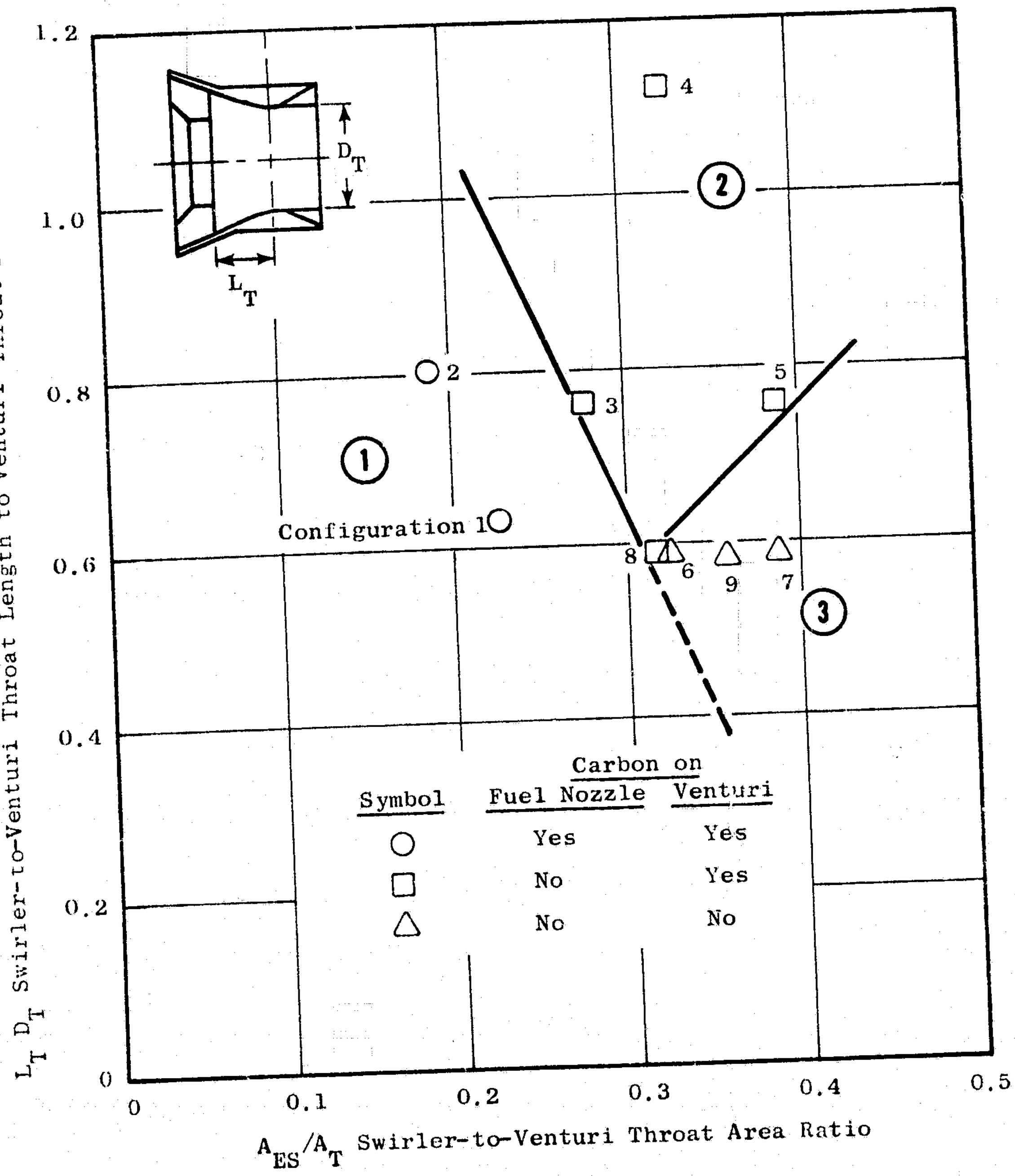


Figure 31. Swirl Cup Carboning Test Results.

engine prototype pilot stage primary swirler design. The final three full annular configurations (D12-D14) exhibited no resonant frequencies at any operating conditions.

Table XXI. Double Annular Combustor Acoustic Resonance Summary.

Configuration	Pilot Stage Primary Swirler	Outer Liner Dilution	Main Stage Swirl Cup Airflow ($\%W_c$)	Resonance at: Idle	High Power
D5	Original	No	48.3	No	Yes
D7-D11	Original	Yes	33.3 - 33.5	Yes	No
D12-D14	Prototype	Yes	30.5 - 33.4	No	No

Combustor Exit Temperature Profile Results - The exit temperature profile characteristics of the Double Annular Combustor were found to be a strong function of fuel flow split between stages. With only the pilot stage fueled, the average profile was strongly outward peaked. With both stages fueled, and the fuel flow highly biased to the inner annulus (about 85% at takeoff), the profile was more nearly symmetrical. Figure 32 shows the wide range of profile factors encountered over the operating range of Configuration D12B. At low power operating conditions such as idle and approach, fairly high profile factors are tolerable due to the low combustor inlet temperature and fuel-air ratio. At climbout and takeoff conditions, profile factors of about 1.1 or below, are mandatory for safe engine operation. As seen in Figure 32, these profile factors were obtained at climbout and takeoff with approximately 20% of the total fuel supplied to the pilot stage. This is also about the fuel split that provides the lowest NO_x levels.

A comparison of the average and peak radial temperature profiles at approach conditions with pilot-stage-only, two-stage uniform, and two-stage sector fueling modes is presented in Figure 33. As shown, the average profiles are somewhat less severe with two-stage operation. However, with both stages uniformly fueled unacceptably high CO and HC levels are produced. With the sector fueling technique, the temperature profile of half of the combustor, corresponding to the sector where the main stage is not fueled, is significantly colder than the average, while the profile of the fueled sector is significantly hotter than the average. Thus, in addition to the radial exit temperature variation and the normal circumferential temperature variations, with sector fueling, the turbine rotor would see significant thermal gradients as each blade entered and left the hot sector. Additional studies would be required to assess the impact on the mechanical performance of the turbine at the moderately high combustor inlet temperature corresponding to the approach operating condition.

The exit temperature profile characteristics of the Phase III combustor prototype configuration (D12) at takeoff conditions with 18% of the fuel

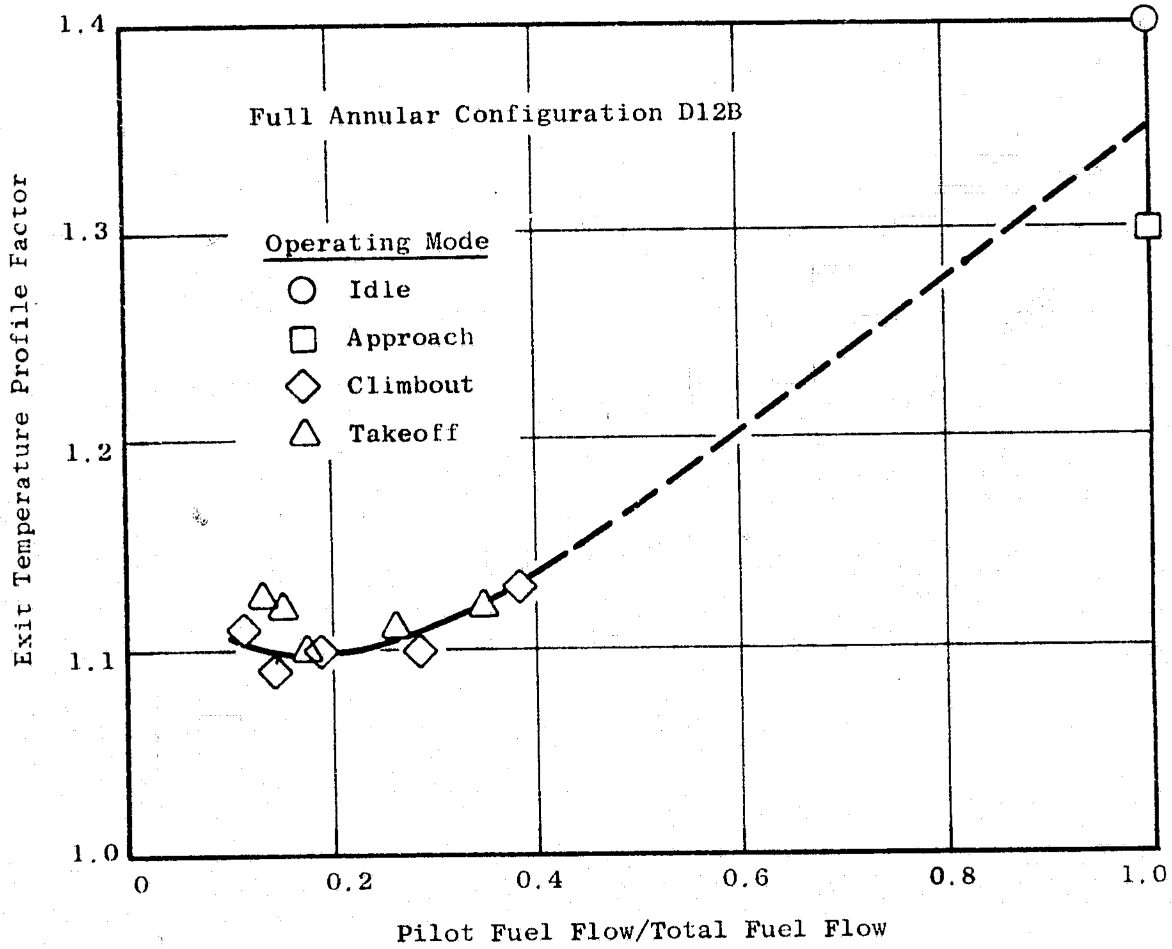


Figure 32. Effect of Fuel Flow Split on Profile Factor for the Double Annular Combustor.

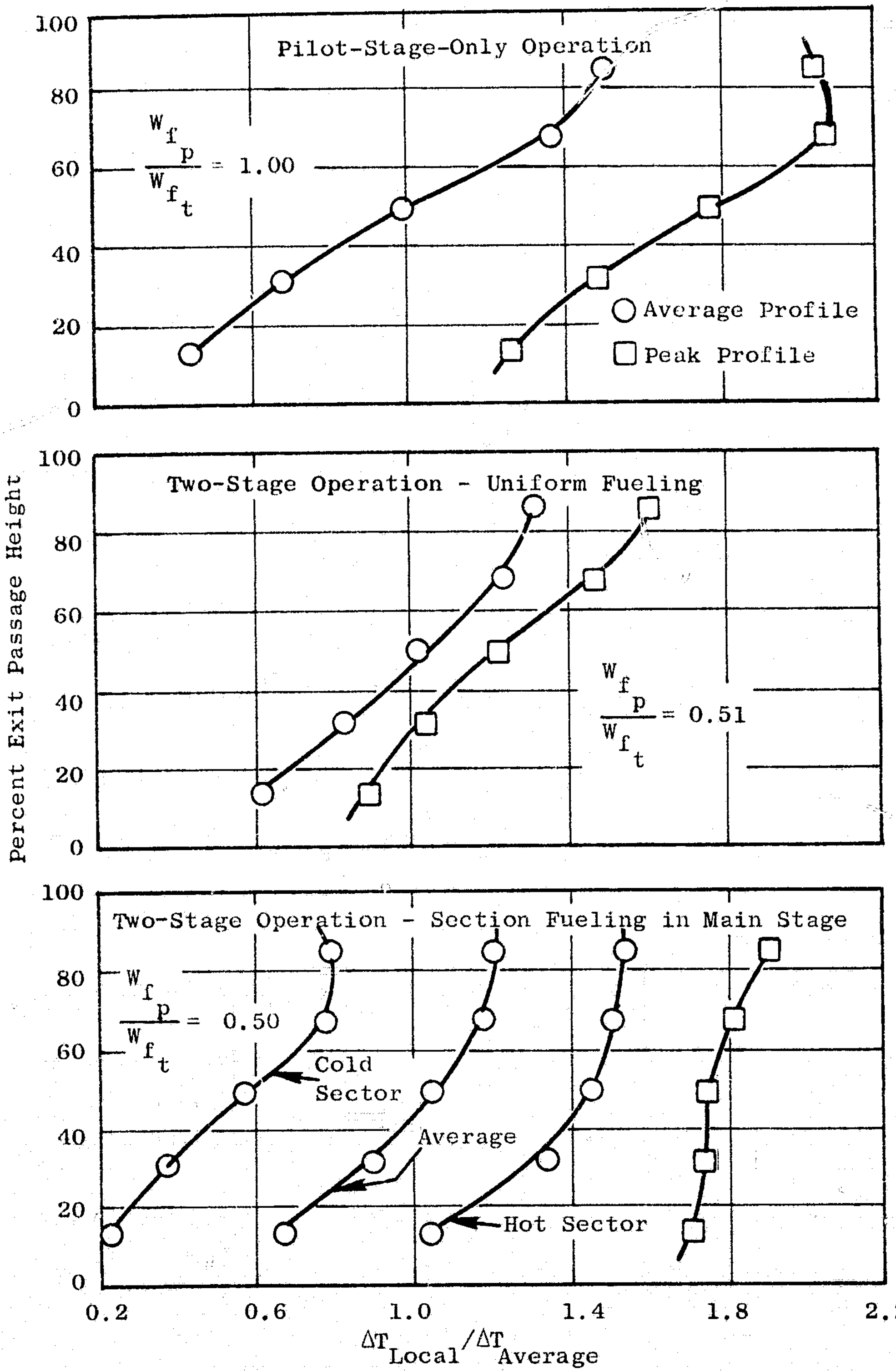


Figure 33. Effect of Fueling Mode on Exit Temperature Profiles of the Double Annular Combustor at Approach Conditions.

supplied to the main stage, are shown in Figure 34. The average profile is more inward-peaked than the production CF6-50 combustor. The profile factor is about 1.1 for each combustor. Peak temperatures are higher for the Double Annular Combustor, especially at the inner immersions. Two values for the peak temperature are shown at the outermost immersion for the Double Annular Combustor. The higher temperature is due to the presence of the centerbody cross-fire slot. The lower temperature is the highest peak temperature at that radial immersion elsewhere in the combustor exit plane. No attempt was made during Phase II to adjust the peak profile characteristics of the combustor. When the engine demonstrator combustor is received during Phase III, a series of tests will be conducted to trim the peak profile to the levels required for engine operation.

Main Stage Cross-Fire Results - Although some difficulties had been encountered with cross-firing the main stages of Configurations D1-D5, ignition was always obtained. For Configuration D6, successful cross-fire ignition of the main stage could not be obtained over wide ranges of inlet temperature, pressure, airflow and fuel flow. A series of tests were conducted in the 60° sector rig which successfully resolved the cross-fire problem.

These tests indicated two sources of concern. First, the lean stability of the main stage swirl cup was poor with a blowout fuel-air ratio of 0.015 at approach inlet conditions and a very unstable flame zone. A return to the lower airflow primary and secondary swirler utilized in Phase I and in Configurations D1 and D2 lowered the lean blowout limit to below 0.005. This swirl cup was incorporated into full annular test configurations D7 - D14.

Second, even with the lower airflow rate in the main stage swirl cups, the fuel-air ratio required to achieve ignition of the main stage was greater than 0.035. A cutout in the centerbody in line with a swirl cup, shown in Figure 18, significantly reduced the cross-fire fuel-air ratio of the combustor. The cross-fire slot was incorporated into the remaining Phase II full annular test configurations, and is also included in the Phase III demonstrator combustor design. With the two modifications, significantly improved main stage ignition and stability characteristics were demonstrated. An extensive mapping of the capabilities of the combustor was undertaken with Configuration D8 which contained the same main stage swirl cup and dilution pattern as D12. Results are shown in Figure 35. Generally, the required main stage cross-fire fuel-air ratio was 0.012 - 0.014, depending on the pilot stage fuel-air ratio, and the lean blowout limit was 0.002 - 0.004.

Summary of Combined Results

Pollution-Performance Tradeoff Considerations - The lowest idle emission levels were achieved with the pilot stage design of Configurations D8-D11. Both CO and HC levels below the program goals were repeatedly obtained. However, the pilot stage swirl cup utilized in these configurations did not meet the altitude relight, carbon or ground start performance requirements and acoustic resonance was encountered at idle conditions.

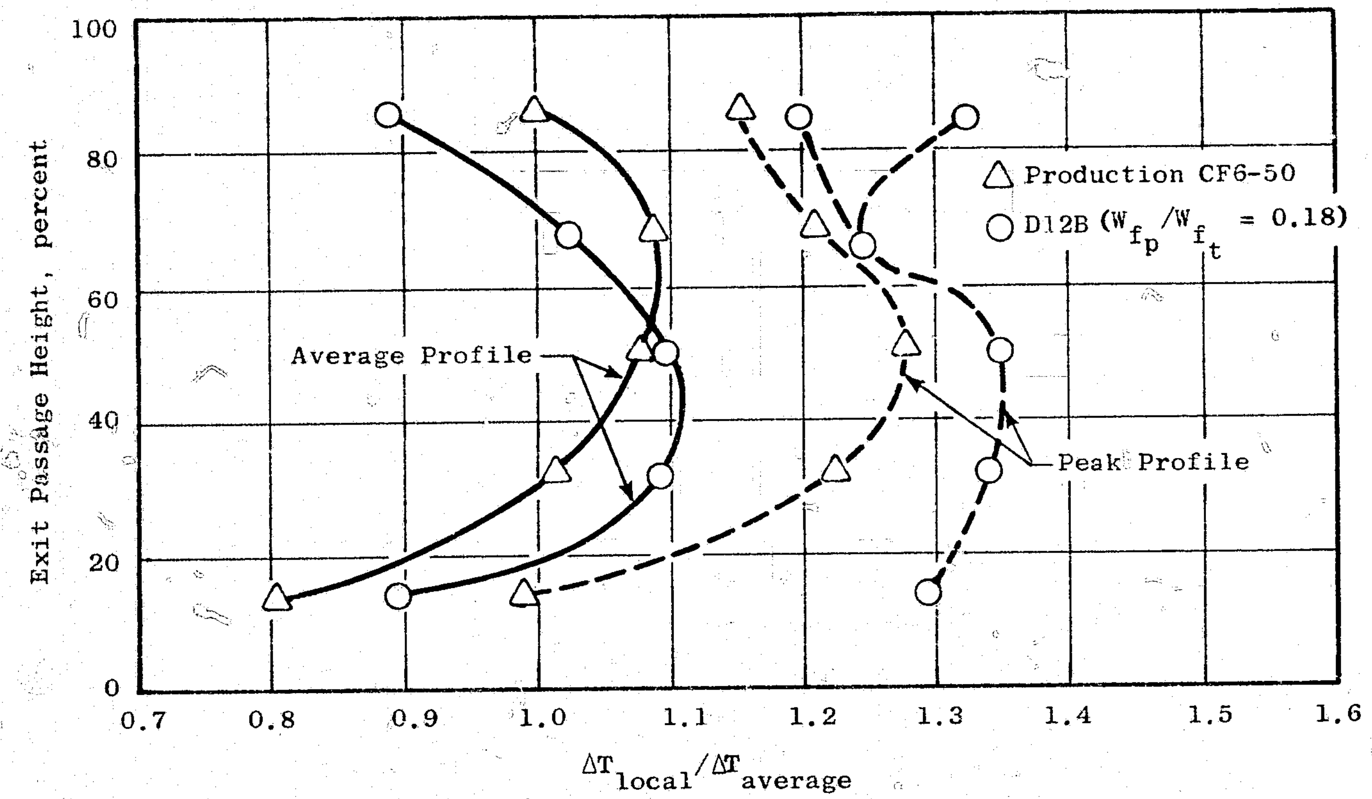


Figure 34. Exit Temperature Profile Characteristics of Final Double Annular Combustor Design Configuration at Takeoff Conditions.

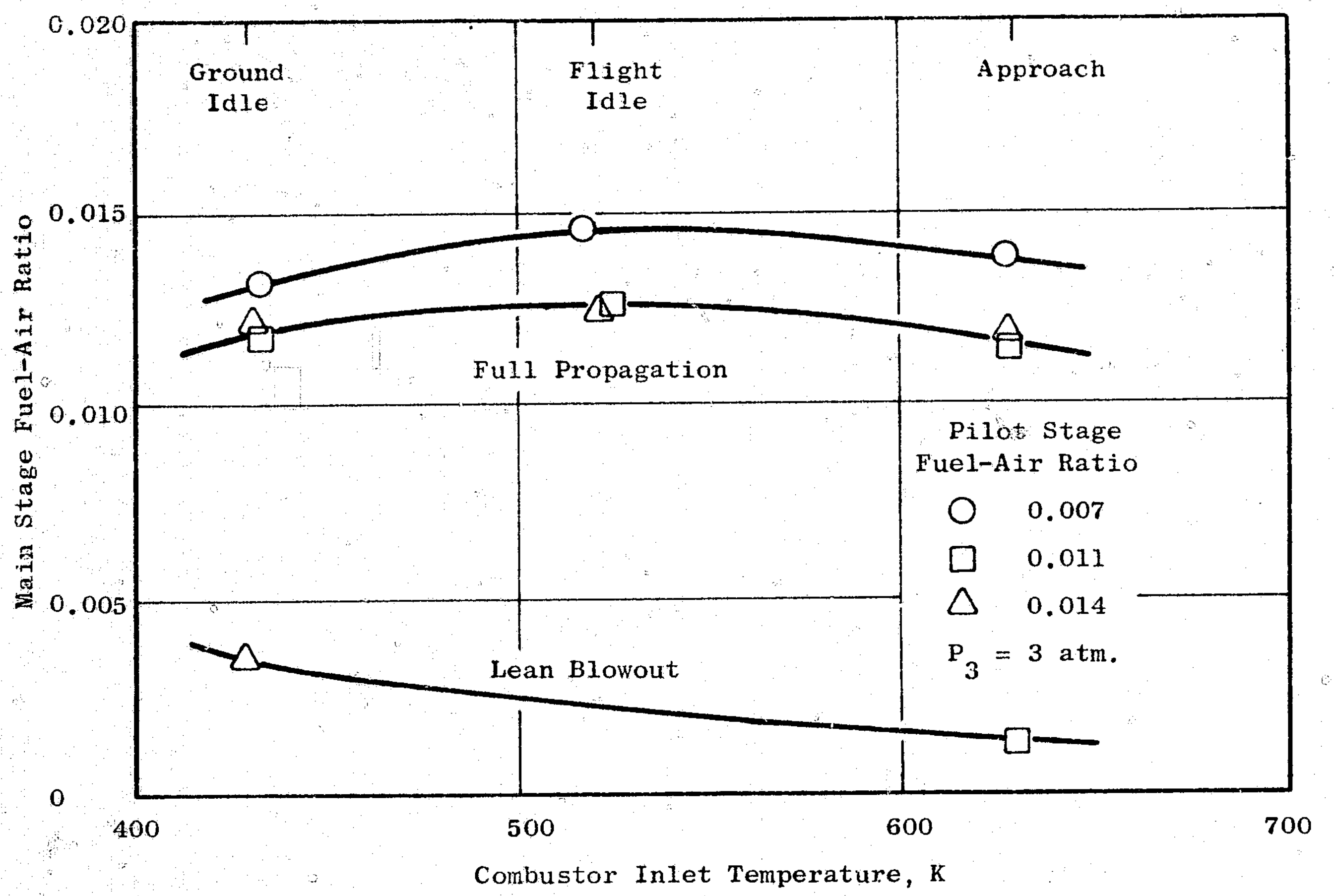


Figure 35. Double Annular Combustor Main Stage Cross-Fire/Stability Characteristics.

The lowest NO_x levels were obtained with Configuration D13 in which 17% of the combustor airflow was used as main stage dilution. For the Phase III engine tests, however, 17% of the airflow will not be available for main stage liner dilution. Due to the higher pressure levels at engine conditions, durability considerations require increased dome cooling airflows. Some aft dilution air must also be provided for trimming the combustor exit temperature profiles.

The additional airflow required for engine-combustor operation is not available from other sources. The liner cooling airflows, the pilot and main stage swirl cup airflows and the outer liner dilution airflows must remain unchanged because of the strong effect of each on the durability, performance, ignition and low power emission levels. It appears that the engine combustor design can incorporate only 10.6% of the combustor airflow as main stage dilution flow, rather than the higher airflow levels of Configuration D13. Configurations which meet this requirement are D7, D8, D10, D11, and D12.

Best Engine-Combustor Compromise Design - The Double Annular Combustor configuration which met or most closely approached all of the emission and performance goals, while adhering to the engine-combustor airflow design constraints was Configuration D12. The pilot stage demonstrated satisfactory sea level and altitude ignition performance and carbon-free and resonance-free operation at all operating conditions. The main stage demonstrated satisfactory cross-fire ignition and stability characteristics, suitable average exit temperature profiles at takeoff and resonance-free operation at all operating conditions, while incorporating a main stage dilution airflow of 10.9% in the first liner panel. The CO and HC EPA parameters of this configuration were below the 1979 standards, and were 3.4 and 0.4 respectively. The NO_x EPA parameter was 4.5. While this value is above the 1979 standard value, it represents a substantial reduction compared to current production CF6-50 values. The Phase III engine demonstrator combustor design has been modeled as closely as possible after Configuration D12.

RADIAL/AXIAL STAGED COMBUSTOR

Phase I Results

The Radial/Axial Staged Combustor produced the lowest CO and HC emission levels at idle and the lowest NO_x emission levels at takeoff of any combustor design tested during Phase I. At idle operating conditions, CO and HC reductions of 62% and 93%, respectively were obtained relative to the production CF6-50 combustor. At takeoff a NO_x reduction of 66% was obtained. The areas of concern with this design at the beginning of Phase II were (1) the performance and emission levels at intermediate power operating conditions; (2) the control of the exit temperature profile characteristics; (3) the possibility of flashback occurring in the premixing main stage; and, (4) the development of satisfactory altitude relight performance and carbon-free operation of the pilot stage with no loss in emissions performance. In addition, further emission reductions were required at idle and takeoff operating conditions to meet the ECCP goals and 1979 EPA standards.

Exhaust Emission Results

The key emission results for all full annular Radial/Axial Staged Combustor configurations at standard day idle, approach, climbout and takeoff operating conditions are summarized in Table XXII. The standard day cruise results are summarized in Table XVIII. As in the Double Annular Combustor tests, a range of fuel flow splits between pilot and main stage was investigated at each operating condition above idle to determine the effect on emission levels. All of these splits are tabulated in Table XXII.

Idle Pollution Results - HC levels below the program goals and CO levels very near the program goals were obtained at the standard day idle condition with this combustor during Phase II. The CO and HC levels of significant configurations are shown in Figure 36 for a range of fuel-air ratios.

The final Phase I configuration had produced idle emission levels significantly higher than any previous configuration. Turning vanes installed in the main stage flameholder array or inserts in the vane passages of the pilot stage secondary swirlers were design changes which might have produced the high idle emission levels. The effects of these two design changes were assessed in the first two Phase II test configurations. The pilot stage of Configuration R1 was essentially identical to the last Phase I configuration, with some of the turning vanes in the main stage flameholder array removed. In Configuration R2, the secondary swirler inserts were removed and four vane passages of the secondary swirler were closed to maintain the correct flow area. As shown in Figure 36, the idle emission levels of Configuration R1 were high, but the levels of Configuration R2 were significantly reduced. This indicated that the secondary swirler vane inserts were responsible for the high idle emission levels. In the 60° sector tests, pressure-atomizing fuel nozzles were found to improve the altitude relight performance of the combustor. Similar nozzles were installed in the full annular combustor for Configuration R4. The resulting HC levels were significantly lower than any previous configuration and met the program goal. The CO levels were reduced from previous Phase II configurations, especially at fuel-air ratios below 0.011. The addition of many small dilution holes in the pilot stage, evaluated with Configuration R6, reduced the CO levels by almost 50% at the design idle fuel-air ratio, and the program goal for CO was closely approached. The HC levels were also slightly lowered. In contrast, to the Double Annular Combustor CO characteristics at idle, the Radial/Axial Staged Combustor produced CO levels which are nearly constant over a wide range of idle fuel-air ratios.

Climbout and Takeoff Pollution Results - The NO_x emission characteristics of this concept were found to be highly dependent on the fuel flow split between stages at the climbout and takeoff operating conditions. As shown in Figure 37, NO_x levels below the program goal at takeoff were achieved with several configurations with the fuel flow highly biased to the main stage. Unlike the Double Annular Combustor, however, as a greater proportion of the fuel was scheduled to the main stage, combustion efficiency decreased along with the NO_x level. In order to maintain high combustion efficiency levels consistent with engine requirements, this design could not be operated at the

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Table XXII. Radial/Axial Staged Combustor Emission Results.

Conf. No.	Idle					Approach						Climbout						Takeoff					
	Rdg. No.	W_{f_p}/W_{f_t}	EI CO	EI HC	EI NO_x	Rdg. No.	P_3 Test atm	W_{f_p}/W_{f_t}	EI CO	EI HC	EI NO_x	Rdg. No.	P_3 Test atm	W_{f_p}/W_{f_t}	EI CO	EI HC	EI NO_x	Rdg. No.	P_3 Test atm	W_{f_p}/W_{f_t}	EI CO	EI HC	EI NO_x
			meas. @ 2.9 atm						corr. to 11.7 atm						corr. to 25.9 atm						corr. to 29.8 atm		
Std. Prod.	-	-	73.0	30.0	2.5	-	-	-	4.3	0	10.0	-	-	-	0.3	0	29.5	-	-	-	0.2	0	35.5
R1	5	1.00(1)	86.8	29.1	2.2	7	3.4	1.00	4.8	0.1	6.3	10	4.8	0.33	18.7	0.4	23.1	13	4.8	0.34	2.8	0.03	32.9
	3	1.00	88.7	26.2	2.3	23	6.8	1.00	5.4	0.2	6.9	9	4.8	0.28	31.4	1.2	16.7	12	4.8	0.25	4.4	0.1	23.1
						24	3.4	1.00(1)	5.4	0.7	5.5	8	4.8	0.23	40.0	2.5	11.2	19	9.6	0.26	6.0	0.1	22.3
						27	3.4	0.53(2)	83.5	27.3	7.9							11	4.7	0.16	16.0	0.5	11.5
						21	6.9	0.53(2)	89.6	40.5	7.7							18	9.6	0.17	15.1	0.5	11.9
						28	3.4	0.42(2)	87.2	45.3	4.8							16	4.8	0.21(1)	11.6	0.6	19.4
						20	6.8	0.42(2)	90.7	58.6	5.0							15	4.8	0.17(1)	18.1	1.5	17.0
						25	3.4	0.47(1,2)	74.3	25.5	5.5							14	4.8	0.13(1)	29.1	3.9	12.1
						22	6.9	0.42(1,2)	77.7	42.9	5.1							17	9.6	0.12(1)	28.5	2.9	12.7
						26	3.4	0.28(1,2)	82.8	49.6	4.0												
R2	61	1.00	53.6	5.7	3.0	66	4.8	1.00	2.1	0.2	9.1	81	4.7	0.34(3)	7.4	0.1	23.2	85	4.6	0.30	1.7	0.03	25.0
						71	4.8	0.43	93.1	38.7	3.6	83	4.8	0.34	6.1	0.1	21.8	86	4.6	0.21	3.7	0.1	18.1
						70	4.8	0.35	82.6	45.1	3.5	82	4.8	0.23(2)	11.3	0.4	14.5	87	4.8	0.17	8.9	0.1	16.4
						73	4.8	0.28	108.1	93.6	1.8	84	4.6	0.23	10.5	0.2	14.2						
						67	4.7	0.54(3)	67.1	17.1	7.8												
						69	4.8	0.42(3)	75.2	30.9	4.6												
						72	4.8	0.35(3)	98.9	56.9	2.6												
R3	129	1.00	51.9	6.7	3.1	135	3.4	1.00	1.4	0.1	7.5	139	4.7	0.33	15.3	0.7	20.7	145	4.7	0.30	4.0	0.1	24.2
						153	6.8	1.00	2.5	0.2	8.0	151	9.5	0.32	18.1	0.6	19.6	148	9.5	0.30	2.1	0.2	23.1
												138	4.7	0.23	33.3	3.6	11.9	144	4.7	0.22	11.0	0.4	17.0
												150	9.5	0.23	32.5	2.8	12.0	147	9.5	0.22	6.1	0.3	14.2
												137	4.7	0.18	46.6	11.1	8.1	143	4.7	0.17	21.9	1.9	13.3
												149	9.5	0.18	49.5	10.0	8.6	146	9.5	0.17	15.0	1.5	11.9
												140	4.8	0.33(3)	13.5	0.4	25.6						
												141	4.7	0.18(3)	29.5	2.6	15.1						
R4	188	1.00	44.8	1.3	3.0	193	3.4	1.00	1.5	0.03	7.6	200	4.8	0.45	30.4	1.0	27.6	204	4.8	0.30	8.6	0.3	21.7
												199	4.8	0.32	35.0	1.5	15.7	203	4.8	0.22	18.3	1.0	12.3
												198	4.8	0.22	48.2	5.4	8.1	202	4.8	0.17	34.0	4.8	8.3
												197	4.8	0.18	58.8	15.3	5.0						
R5	211	1.00	40.4	2.2	3.0	215	3.4	1.00	1.3	0.03	8.5	223	4.8	0.33	21.8	0.8	11.4	225	4.7	0.22	17.5	2.2	10.0
												220	4.8	0.23	32.3	3.3	6.3	224	4.7	0.18	23.1	2.0	7.9
												219	4.7	0.19	52.2	15.4	4.5						
R6	260	1.00	23.9	0.3	2.8	263	3.5	1.00	1.0	0.03	9.3	271	4.8	0.33	6.7	0.6	13.6	-	-	-	-	-	-
						267	3.6	0.50	112.5	62.6	2.9												
						266	3.5	0.35	81.3	112.1	1.3												
R7	377	1.00	48.8	7.9	2.6	392	3.4	1.00	0.8	0.1	6.4	398	4.7	0.32	27.4	2.2	7.2	400	4.7	0.25	13.0	0.7	9.7
												397	4.7	0.23	59.2	18.0	3.0	399	4.8	0.21	35.4	5.3	6.8
												396	4.7	0.18	41.4	34.2	1.6	401	9.5	0.21	27.4	5.9	7.6

(1) Alternate pilot injectors fueled
(2) Alternate pairs of main injectors fueled
(3) Alternate main injectors fueled

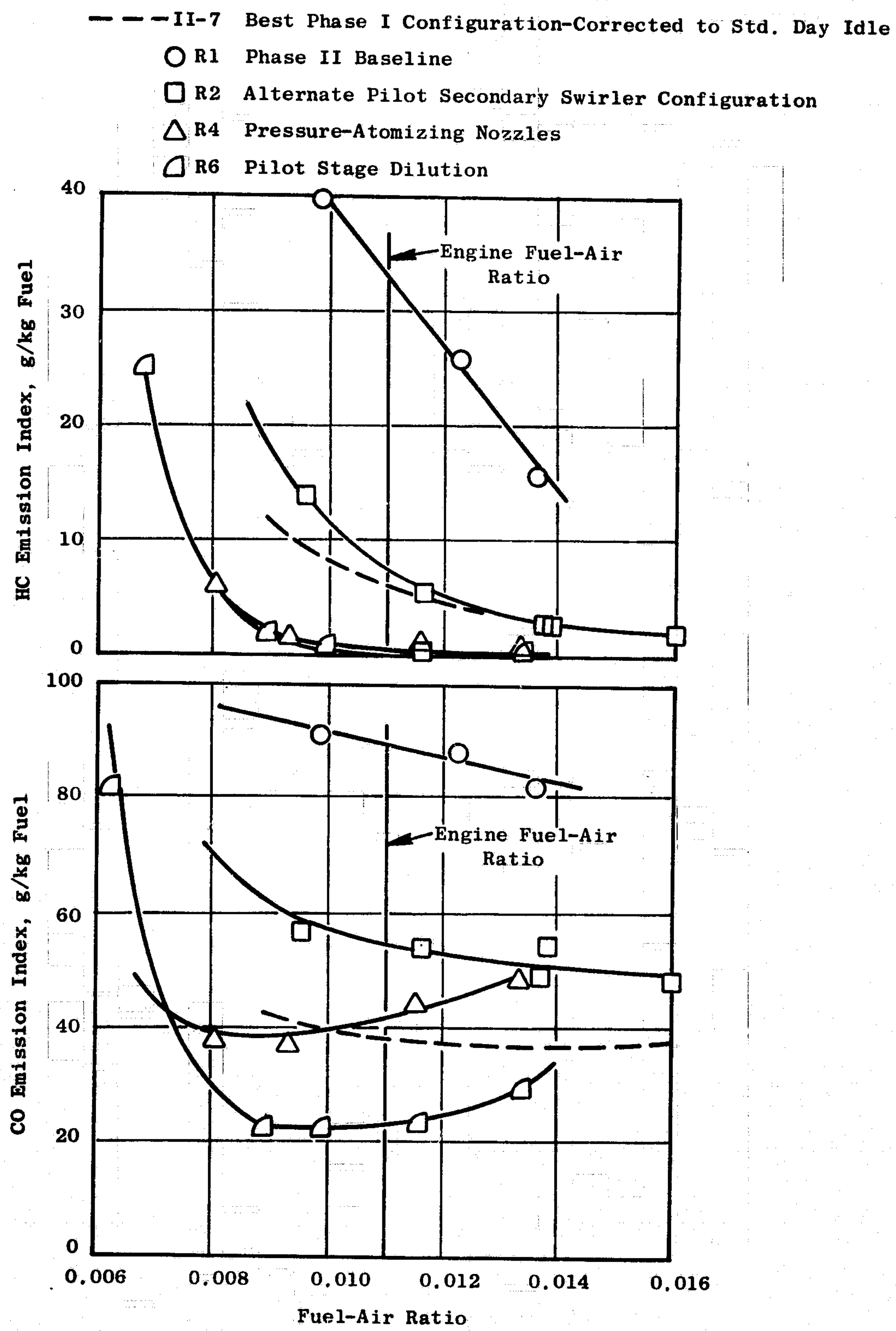

Figure 36. Radial/Axial Staged Combustor Idle Emission Characteristics.

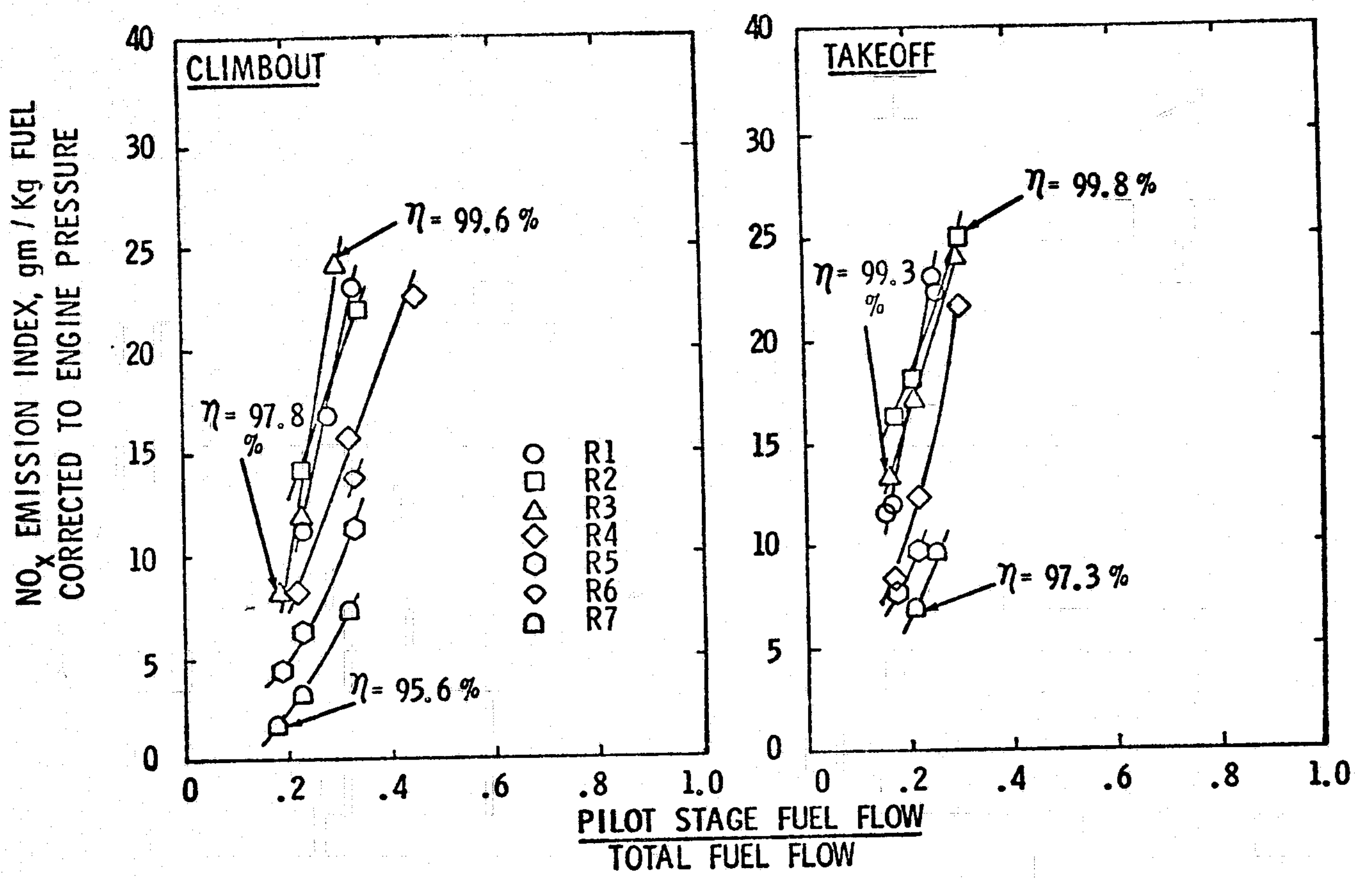

Figure 37. Effect of Fuel Flow Split on NO_x Emission Levels of the Radial/Axial Staged Combustor at Climbout and Takeoff Conditions.

fuel flow split which produced the lowest NO_x level. As shown in Figure 38, a direct tradeoff between NO_x level and CO level exists. In order to assess the effects of design changes on emission levels, the NO_x levels of different configurations must be compared at the same CO (or efficiency) level if meaningful conclusions are to be drawn. The differences between configurations tended to be more pronounced at climbout conditions than at takeoff.

Three principal approaches for increasing combustion efficiency levels at high power operating conditions while maintaining low NO_x production were investigated. These were: varying the amount of main stage airflow passing through the premix passage; varying the flame holder wetted perimeter; varying the premix passage length.

Main stage premix passage airflows were 64 percent for R1, 18 percent for R2 and R6, and 47 percent for R5 and R7. Results of varying premix passage airflow can be seen in Figures 37 and 38. Both R2 and R6 showed significant improvements in NO_x and CO levels compared to R3 especially at the climbout condition. However, flashback was encountered with Configuration R6. Configurations R5 and R7 produced CO and NO_x levels lower than Configuration R1, but somewhat higher than Configurations R2 and R6. Flashback was encountered with Configuration R5.

The effect of increasing the wetted perimeter of the flameholder array by doubling the number of flameholders to promote mixing, can be assessed by comparing the test results of Configurations R1 and R3. A slight improvement in NO_x and CO was indicated at climbout with the 120 flameholder array of Configuration R3. No significant difference was noted at takeoff.

The effect of increasing the premixing length can be determined from a comparison of the test results of Configuration R2 versus R6, R3 versus R4, and R5 versus R7. For Configurations R2 and R6, and Configurations R5 and R7, increasing the premixing length by shortening the main stage fuel tube length produced no noticeable change in the NO_x or CO emission levels at climbout or takeoff. For Configurations R3 and R4, the increased premixing length of R4 resulted in higher CO and NO_x levels, particularly at climbout. The very high main stage airflow (about 65%) and the improved mixing resulted from the added mixing length, apparently produced a mixture which was too lean for efficient combustion.

The smoke levels of all test configurations of this combustor were very low at high power operating conditions (Appendix C), generally below a smoke number of two. Although somewhat higher levels would be expected at engine pressures, the smoke levels of this combustor should not be a source of concern.

Approach Pollution Results - Several fuel staging techniques were examined at approach. These techniques included: (1) fueling all injectors of both stages, (2) fueling all injectors of the pilot stage, and either alternate or alternate pairs of injectors of the main stage, (3) fueling alternate injectors of the pilot stage and alternate pairs of injectors of the main stage, and (4) fueling the pilot stage only. Results are presented in Figure 39.

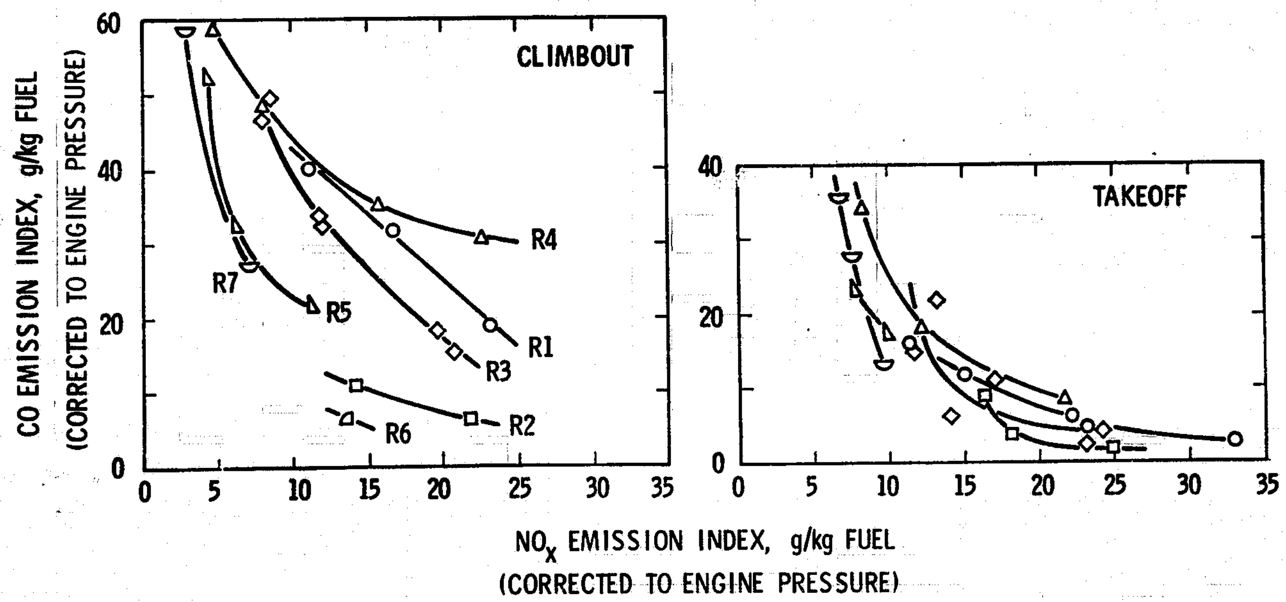

Figure 38. Tradeoff Between NO_x and CO Emissions at Climbout and Takeoff Conditions for the Radial/Axial Staged Combustor.

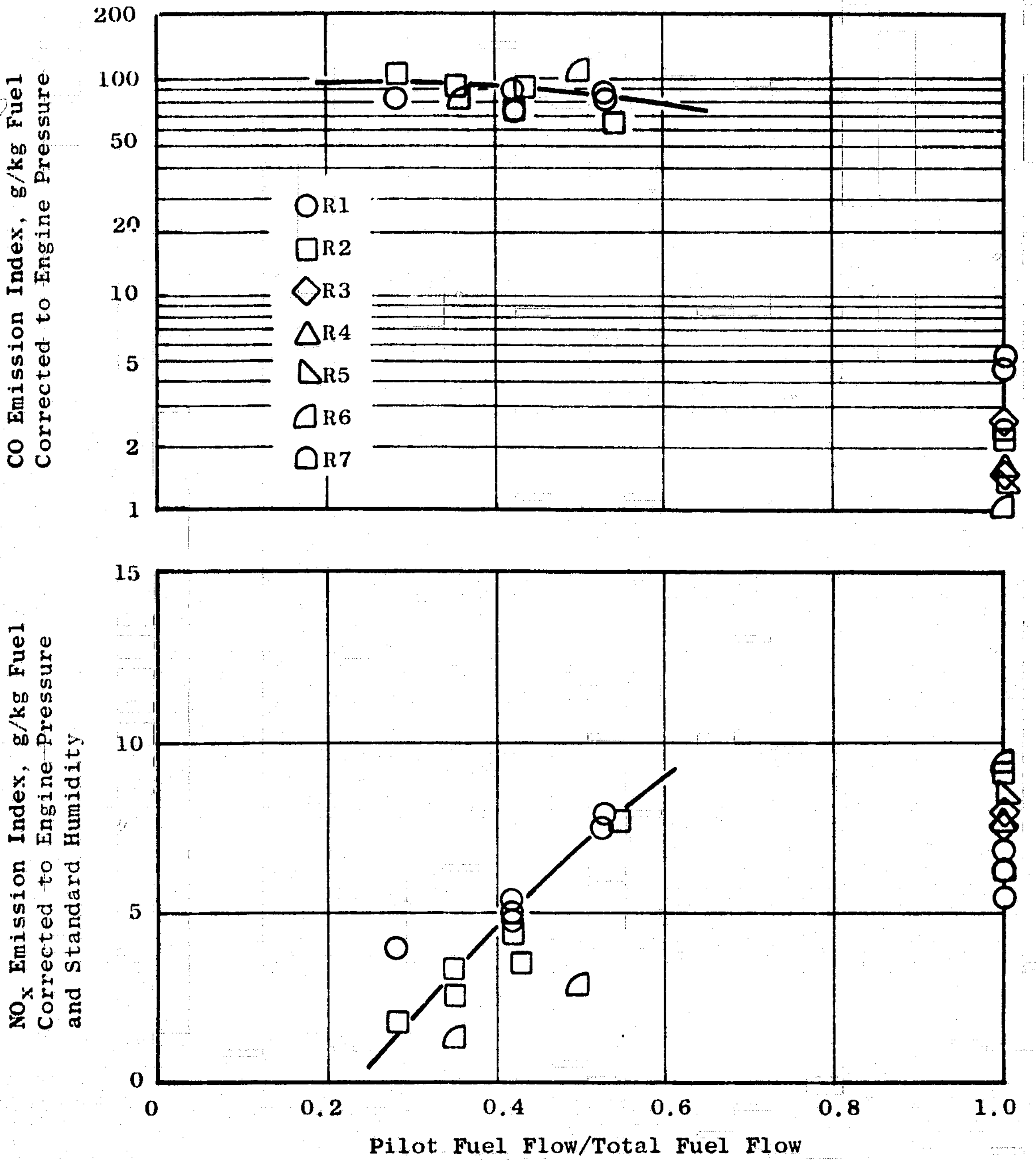

Figure 39. Effect of Fuel Flow Split on Emission Levels of the Radial/Axial Staged Combustor at Approach Conditions.

The first three techniques produced high CO levels, with no discernible differences between the results obtained with each two-stage fueling mode tested. None of the two stage fueling modes shows any promise of achieving the 1979 EPA CO emission standard. As with the Double Annular Combustor, pilot-stage-only operation at approach appears mandatory with the Radial/Axial Staged Combustor to achieve the standards.

Cruise Pollution Results - The emission levels at the standard day cruise condition are summarized in Table XVIII. As noted in the table, some of these data are extrapolated from the climbout test points. All configurations produced NO_x levels below those of the production CF6-50 combustor, but the combustion efficiency levels were also somewhat lower. Tradeoffs between NO_x levels and combustion efficiency are shown in Figure 40. Generally, the best results were obtained with Configurations R2, R5, R6, and R7, all of which had decreased main stage airflow levels. At a combustion efficiency of 99%, a NO_x emission index of about 7 was obtained with these configurations. Although the emission levels at the cruise condition are not currently regulated, very high combustion efficiencies must be maintained at this flight mode in order to maintain current CF6-50 fuel economy performance.

EPAP Results - The status of each Phase II test configuration relative to the 1979 EPA standards is shown in Figure 41. Data from several Double Annular Combustor configurations are also included for comparison. All data are for pilot-stage-only operation at the approach condition. Data for each Radial/Axial Staged Combustor configuration are presented as multi-point curves rather than single points to include different pilot to main stage fuel splits at climbout and takeoff. Table XXIII presents a summary of EPA parameter results for the fuel splits which produced the lowest CO/HC EPA parameters, the lowest NO_x EPA parameters and the lowest combined parameters for each configuration.

With pilot-stage-only operation at approach, several Radial/Axial Staged Combustor configurations meet the HC standard. Several configurations would also meet the NO_x standard, but at the expense of the CO standard. No single configuration approached the CO standard, even though excellent CO levels were obtained at idle. Unlike the Double Annular Combustor, where nearly all of the EPA parameter CO level came from the idle flight mode contribution, nearly half of the CO EPA parameter level of the Radial/Axial Staged Combustor was produced at climbout and takeoff. Configuration R6 showed the most promise of approaching the CO standard, but flashback was encountered and data at all the flight modes were not obtained. If the pilot stage emission levels at idle and approach for Configuration R6 are combined with the emission levels at climbout and takeoff from Configuration R2, which had essentially the same main stage configuration, CO, HC and NO_x EPA parameters of 5.4, 0.1 and 4.3 could be obtained. An alternate fuel split at climbout and takeoff would reduce the CO EPA parameter to 4.4 but the NO_x EPA parameter would climb to 5.9.

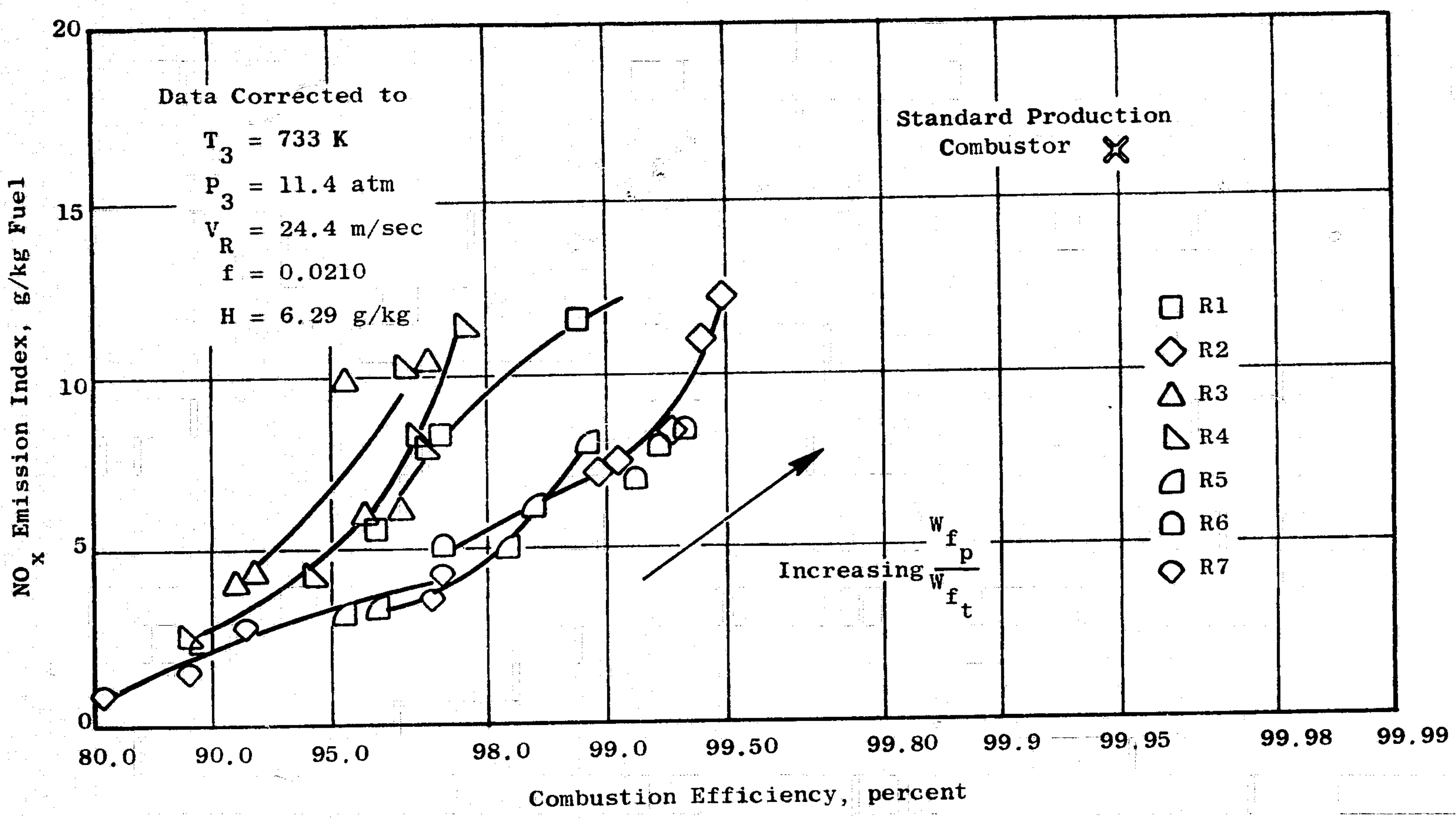

Figure 40. Tradeoff Between Combustion Efficiency and NO_x Emission Level at Cruise Conditions for the Radial/Axial Staged Combustor.

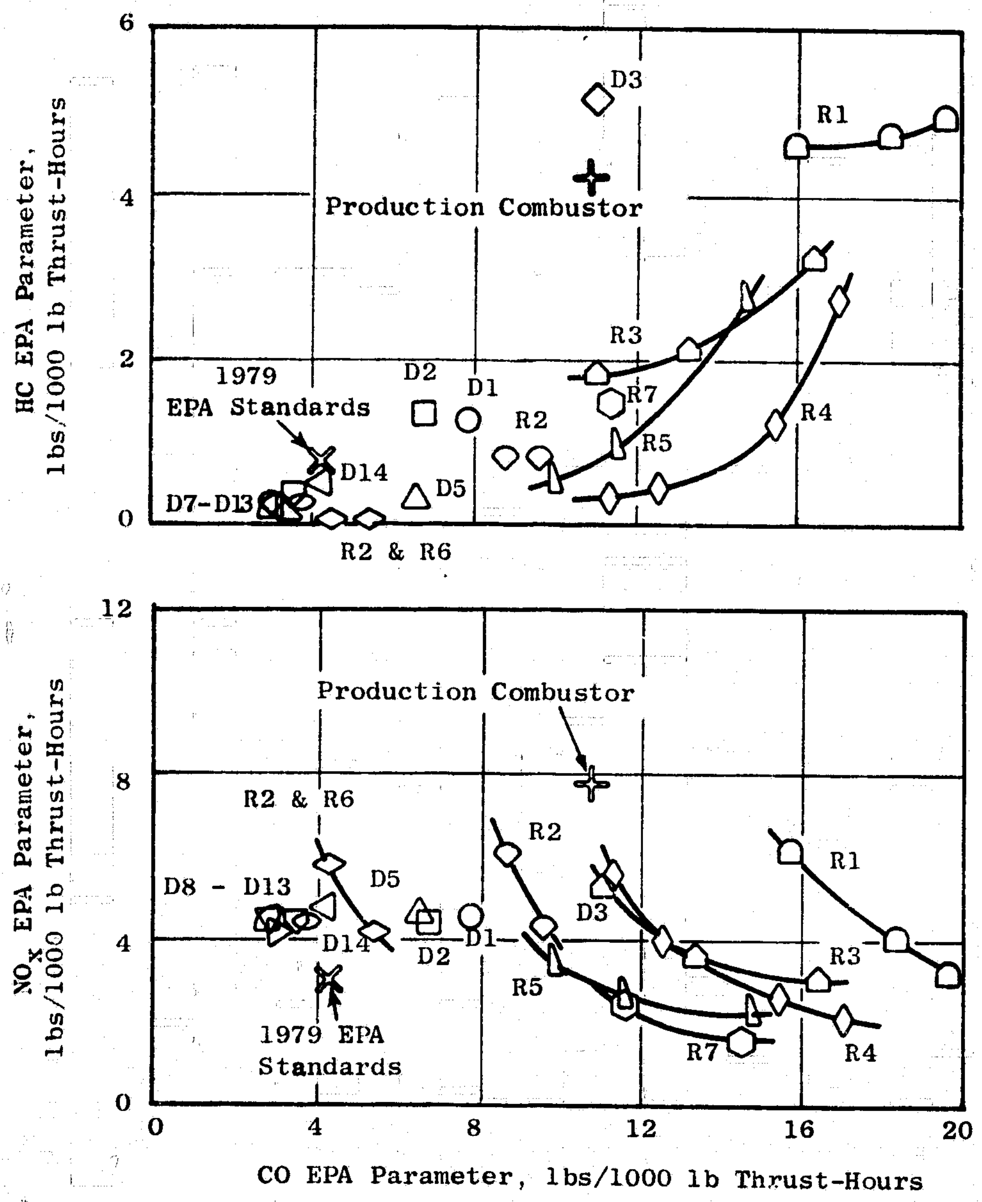

Figure 41. **EPA Parameter Tradeoffs for the Radial/Axial Staged Combustor.**

Table XXIII. Radial/Axial Staged Combustor EPA Emission Parameters.

Configuration	Pilot/Total Fuel Split Idle	App.	Climb	T/O	EPAP (lb/1000 lb thrust-hrs) CO	HC	NO_x	Comments
Std. Prod.	-	-	-	-	10.8	4.3	7.7	
R1	1.00	1.00	0.33	0.34	15.7	4.6	6.2	Low CO/HC
	1.00	1.00	0.28	0.17	18.3	4.7	4.1	Intermediate
	1.00	1.00	0.23	0.17	19.6	4.9	3.2	Low NO_x
	1.00	0.42(1)	0.28	0.17	24.9	8.6	3.9	Approach staging
R2	1.00	1.00	0.34	0.30	8.5	0.8	5.9	Low CO/HC
	1.00	1.00	0.23	0.30	9.2	0.8	4.8	Intermediate
	1.00	1.00	0.23	0.17	9.6	0.8	4.3	Low NO_x
	1.00	0.54(2)	0.23	0.17	15.5	2.4	4.2	Approach staging
R3	1.00	1.00	0.32	0.30	11.0	1.8	5.4	Low CO/HC
	1.00	1.00	0.23	0.22	13.3	2.1	3.7	Intermediate
	1.00	1.00	0.18	0.17	16.4	3.2	3.1	Low NO_x
R4	1.00	1.00	0.45	0.30	11.3	0.3	5.6	Low CO/HC
	1.00	1.00	0.22	0.22	14.5	1.0	2.9	Intermediate
	1.00	1.00	0.18	0.17	17.0	2.7	2.2	Low NO_x
R5	1.00	1.00	0.33	0.22	9.9	0.5	3.4	Low CO/HC
	1.00	1.00	0.23	0.22	11.4	0.9	2.7	Intermediate
	1.00	1.00	0.19	0.18	14.7	2.7	2.3	Low NO_x
R6(3)	-	-	-		-	-	-	
R7	1.00	1.00	0.32	0.25	11.6	1.5	2.6	Low CO/HC
	1.00	1.00	0.18	0.21	14.5	6.5	1.6	Low NO_x
R2/R6(4)	1.00	1.00	0.34	0.30	4.4	0.06	5.9	Low CO/HC
	1.00	1.00	0.23	0.30	5.0	0.08	4.8	Intermediate
	1.00	1.00	0.23	0.17	5.4	0.08	4.3	Low NO_x
	1.00	0.50	0.23	0.17	15.6	5.8	3.7	Approach staging

(1) Alternate pilot stage injectors and alternate pairs of main stage injectors fueled

(2) Alternate main stage injectors fueled

(3) Incomplete test

(4) Idle and approach data from R6 combined with climb and takeoff data from R2

Combustor Performance Results

The key performance parameters for each full annular and sector configuration tested are tabulated in the detailed data summary tables in Appendix C and D.

Altitude Relight Results - The first Phase II Radial/Axial Staged Combustor configuration had poor altitude ignition characteristics, as shown in Figure 42. Almost a 5 km altitude deficiency existed at low flight Mach numbers, with the low pressure drop, airblast fuel injector design. When pressure-atomizing nozzles were installed in the pilot stage, with essentially no other change in swirl cup configuration, successful lightoffs were obtained over nearly the entire required windmilling map. However, the required fuel flows were higher than the target level of 249 kg/hr. An alternate downstream ignitor location was evaluated in the sector tests, and as shown in Figure 42, the altitude relight requirements were met. Thus, with an alternate ignitor location, satisfactory relight performance was obtained with this combustor design.

Ground Start Results - The sea level ignition and subidle temperature rise characteristics of Configuration R7 are shown in Figure 43. Temperature rise characteristics similar to those of the production CF6-50 combustor were obtained over a wide range of fuel-air ratios, thus assuring good subidle acceleration characteristics. The fuel flows required for sea level ignition are slightly higher than the CF6-50 engine minimum scheduled fuel flow, and the lean blowout limits are somewhat high, especially at the high combustion air flows. It should be noted, however, that this configuration did not utilize the same pilot stage swirl cups as the final Double Annular Combustor design, since the Radial/Axial Staged Combustor testing was terminated midway through Phase II. It is expected that with the final Double Annular pilot stage swirl cups, satisfactory sea level ignition and efficiency characteristics would be obtained with this combustor.

Carboning Results - The carbon-free swirl cup evolution, discussed in the Double Annular Combustor section of this chapter, is directly applicable to the Radial/Axial Staged Combustor as well. The primary swirler developed in these tests was not tested in a Radial/Axial Staged Combustor full annular test, since the testing of this combustor was terminated before development of the carbon-free swirl cup was completed. It would be expected, however, to produce carbon-free operation in the pilot stage of the Radial/Axial Staged Combustor.

Flashback Results - Three 12° sector combustor configurations, simulating annular Configurations R3, R5, and R7 were tested to assess the capability of this concept to avoid flashback. The key features investigated were the safety of increased premixing length of R5 and the reduced main stage airflow of R5 and R7. More severe combustor inlet conditions were tested in these sector tests than were achievable in the annular tests. Combustor inlet pressures and temperatures up to 15 atm and 830 K were investigated. No flashback or auto-ignition was obtained in these sector tests over a range of main stage fuel-air ratios up to 0.022.

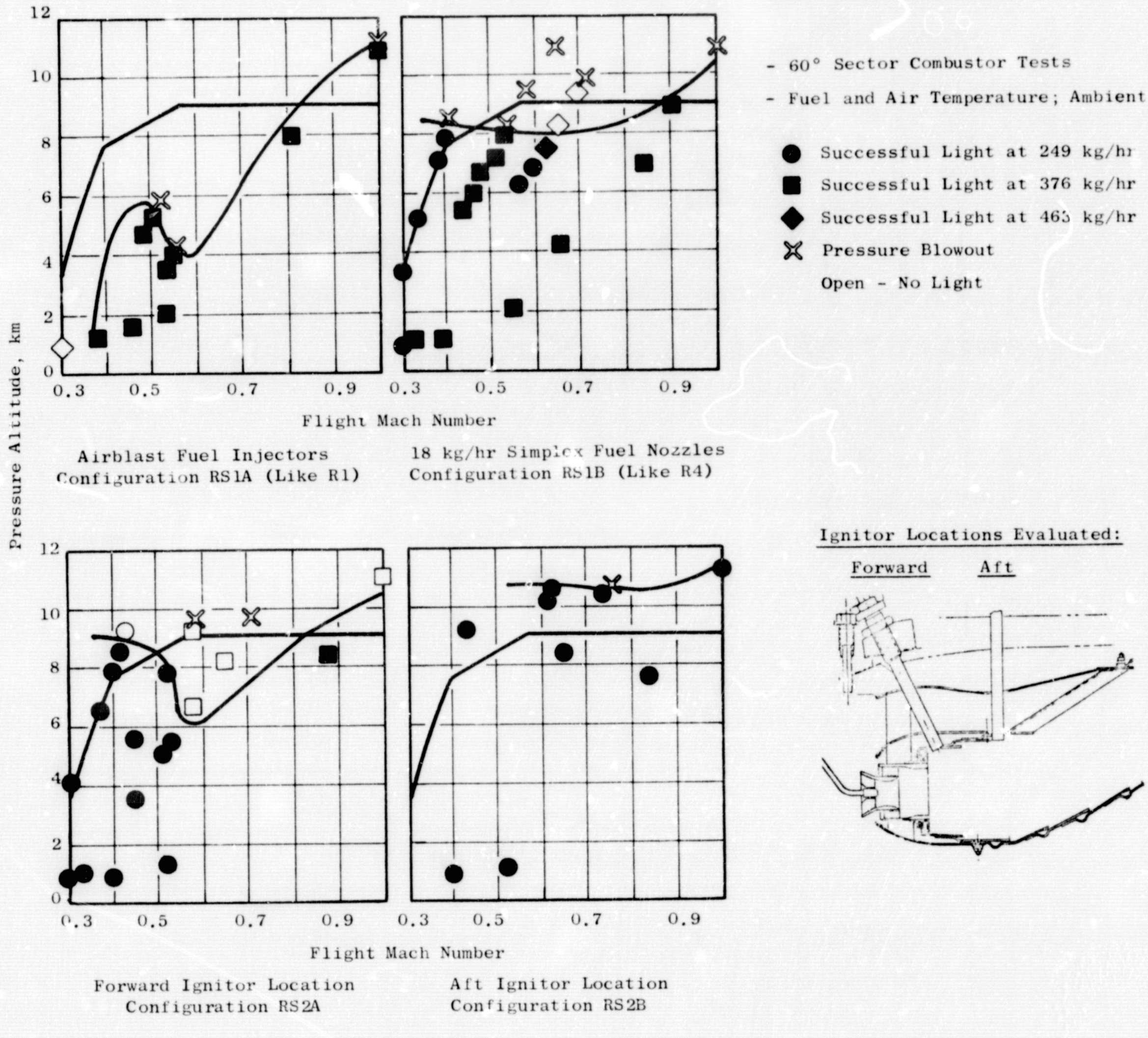

Figure 42. Effect of Design Modifications on Radial/Axial Staged Combustor Relight Characteristics.

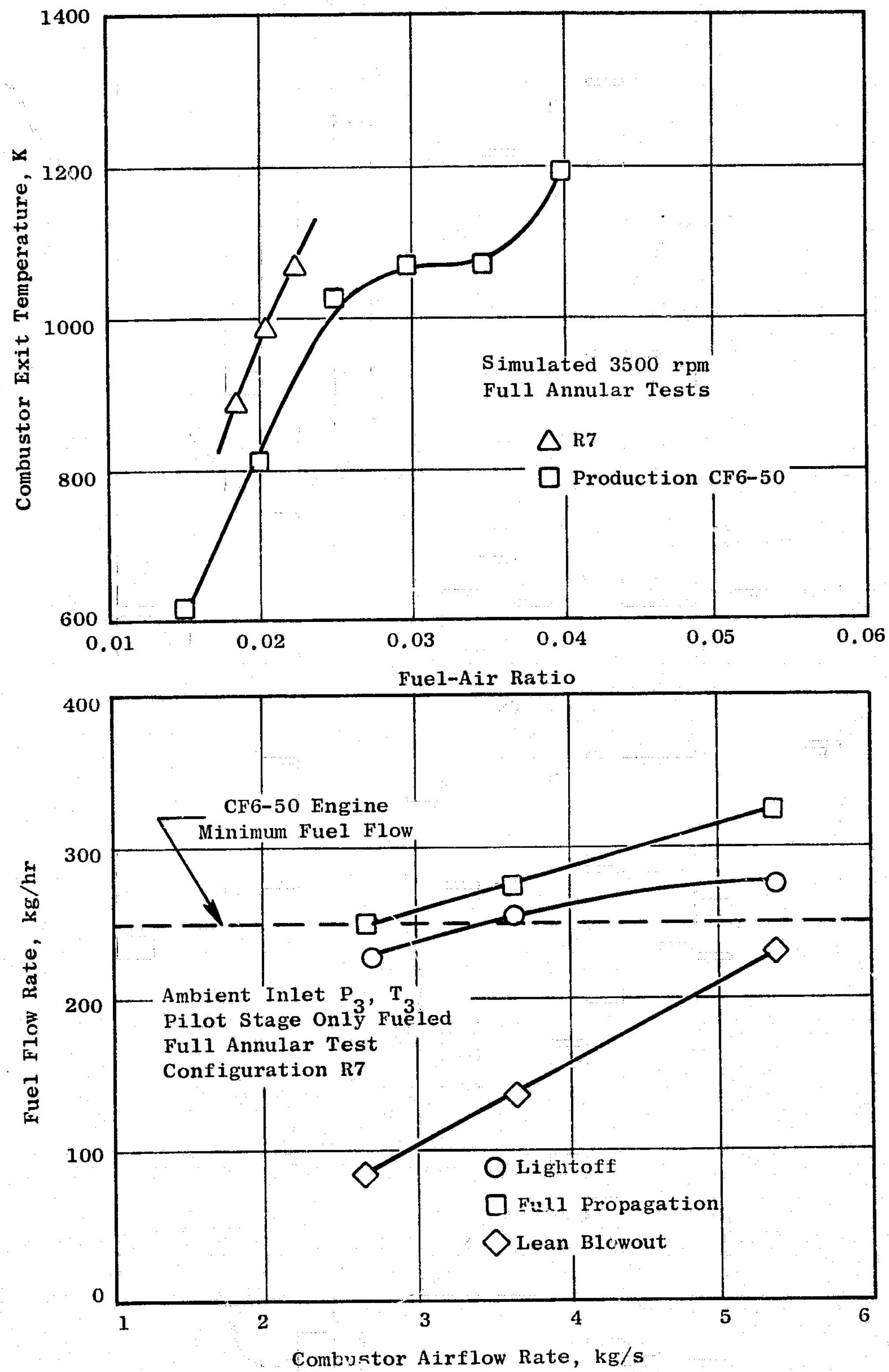

Figure 43. Sea Level Ignition Performance of Final Radial/ Axial Staged Combustor Configuration.

However, flashback was encountered in the full annular tests. Two annular configurations, R5 and R6, experienced burning in the main stage premixing passage resulting in combustor damage. Configuration R5 incorporated the 120 chute flameholder array in the main stage, with the openings between flameholders reduced by flamespraying to provide less main stage airflow. An equivalent amount of area was opened in the 4th panel of the main stage liner to maintain the total combustor open area at the desired level. Indication of upstream burning was obtained at simulated takeoff conditions of 4.8 atm and 820 K. Posttest examination of the hardware showed the flameholders to be burned in several circumferential locations. Analyses of the burn patterns led to the conclusion that the main stage dilution airflow was probably the cause of the damage. Indications were that the dilution airflow, which was located directly across from the flameholders, forced the hot pilot stage gases against the chutes, causing them to overheat. They subsequently melted and allowed the combustion gases to enter the premixing passage. This explanation is substantiated by the observance of several flameholders which were scorched on the downstream side but in good condition on the upstream side. During previous configurations, the flameholder metal temperatures were generally very low. The inner liner dilution air was not included in the 12° sector configuration simulating R5, since the sector test was run prior to the inclusion of the dilution holes in the annular combustor.

Configuration R6 incorporated a splitter in the main stage airflow passage which allowed only a portion of the main stage airflow to be fueled (see Figure 21). Upstream burning was indicated at the climbout condition during full annular testing. Posttest inspection revealed damage in several circumferential locations. From examination of the hardware, it appears that the main stage fuel tubes created a wake along the surface of the airflow splitter. The flame propagated into the premixing passage in the low velocity wake region. A posttest view of the flow splitter is shown in Figure 44. In this photograph, which is a view from the cold side (OD) of the splitter, a typical fuel tube wake and resulting metal discoloration and damaged flameholder can be clearly seen.

It appears that this combustor concept has a tendency to flashback, which can be triggered by small details in the hardware design. This tendency would be enhanced by lower main stage airflows, which are required to provide a suitable high power combustion efficiency level, due to the richer stoichiometry in the premixing passage. Additional design effort is required with this combustor to assure a completely safe, premixing design suitable for engine operation.

<u>Combustor Exit Temperature Profile Results</u> - The combustor exit temperature profile characteristics of this combustor were generally very good. Unlike the Double Annular Combustor, the exit temperature profile factor is not a strong function of the fuel flow split between stages, as shown in Figure 45, due to the intense radial mixing promoted by the sloping flameholder arrays. Even with only the pilot stage fueled, profile factors of about 1.07 resulted, compared to 1.3-1.4 with the Double Annular Combustor.

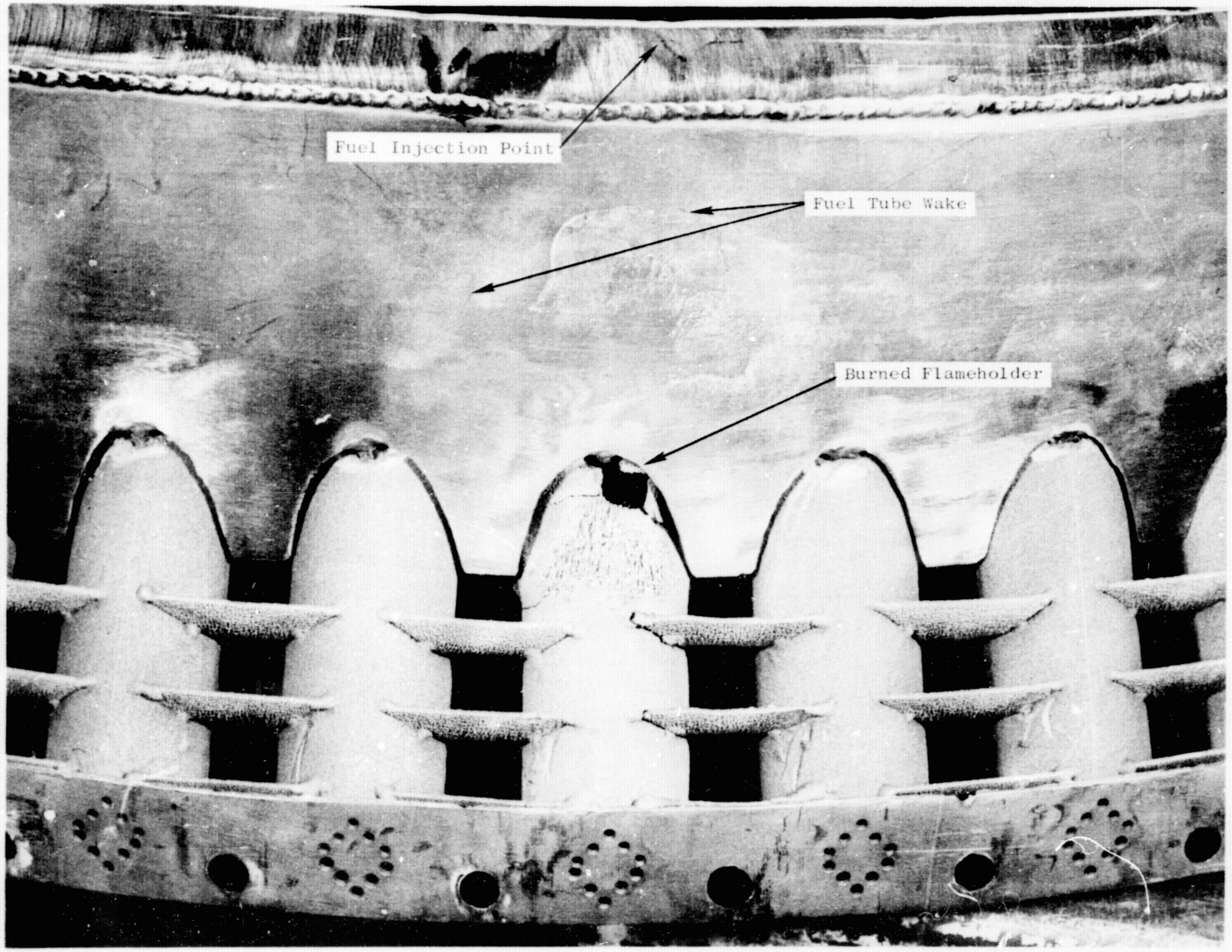

Figure 44. Damaged Radial/Axial Staged Combustor Flameholder Array.

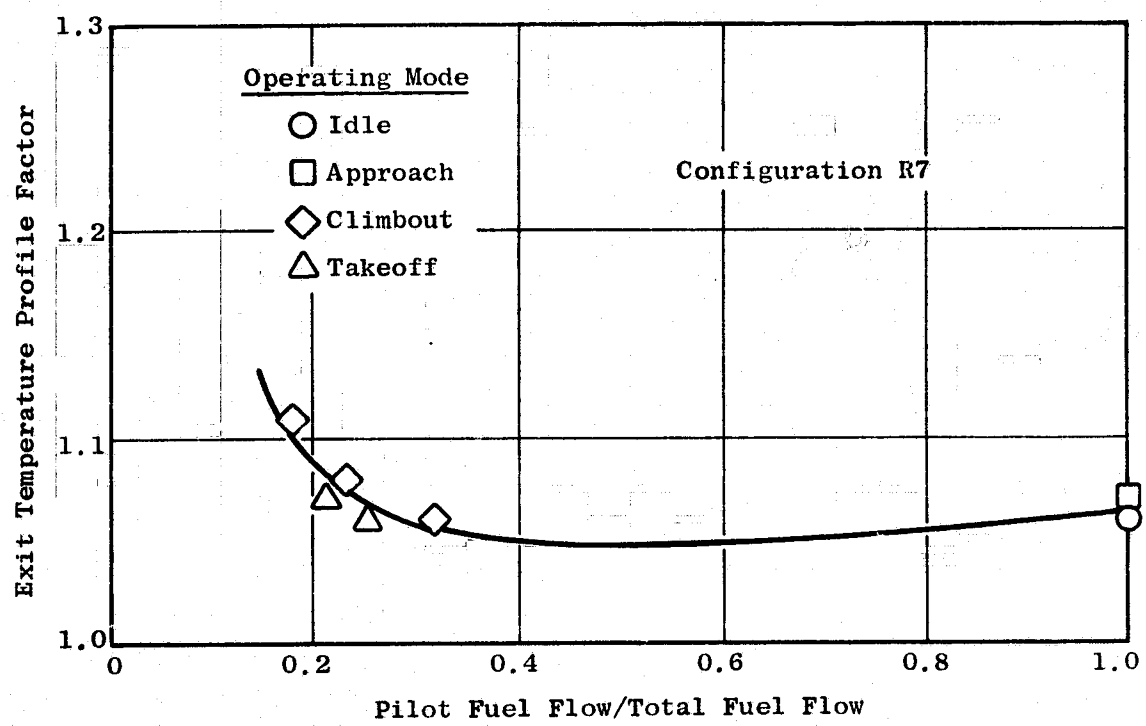

Figure 45. Effect of Fuel Flow Split on Profile Factor for the Radial/ Axial Staged Combustor.

The profile shape at takeoff conditions with 79% of the fuel supplied to the main stage, is shown in Figure 46 for the final configuration. The average profile is somewhat more inward-peaked than the production combustor, but the maximum average profile temperature rise ratio is slightly lower. The peak temperatures were higher for R7, especially at the inner immersions, but no attempts were made during Phase II to adjust the peak profile of the combustor.

Other Performance Results - Other performance aspects of this combustor were excellent. In particular, the ignition of the main stage was always very smooth, with no ignition problems encountered. Because of the geometric positioning of the two combustor stages within this design, the hot gases from the pilot stage are in close contact with the main stage fuel-air mixture. This results in excellent piloting action. No evidence of acoustic resonance was encountered during Phase II with either pilot stage only or two-stage operation. Except for the damage resulting from the two flashback incidences, the mechanical condition of this combustor was very good at the completion of testing.

Summary of Combined Results

Pollution-Performance Tradeoff Considerations - The lowest idle emission levels were obtained with Configuration R6. HC levels were well below the program goals and CO levels were near the program goal with this configuration. All Phase II configurations tested produced much lower NO_x levels than the production combustor at high power operating conditions, but generally with reduced combustion efficiencies. As shown in Figure 47 strong tradeoffs exist at climbout and takeoff between NO_x and combustion efficiency. At the ECCP program target efficiency level of 99%, Configurations R5 and R7 produced lower NO_x levels than any other configurations tested during Phase II. With either configuration, NO_x emission indices at climbout and takeoff were about 6.3 and 7.5, respectively, at the 99% efficiency level. This represents a NO_x reduction of almost 80% from the production combustor. The takeoff NO_x level is also 25% below the program goal.

However, in order to meet the 1979 EPA Emissions Standards, combustion efficiencies significantly higher than 99% are required at the high power operating conditions due to the high engine fuel flows. If the CO and HC standards are to be met, efficiency levels of about 99.8% or higher, are required at the climbout and takeoff conditions.

Best Engine-Combustor Compromise Design - Configuration R2 produced high combustion efficiencies at climbout and takeoff while still providing significant NO_x reductions relative to the production combustor. Configuration R6 also showed promise at climbout, but flashback was encountered, and most of the high power test points were not obtained. The pilot stage configuration of R6, combined with the main stage configuration of R2, appears to be the most attractive Radial/Axial Staged Combustor design combination in terms of approaching all of the 1979 EPA Standards. With this hybrid configuration,

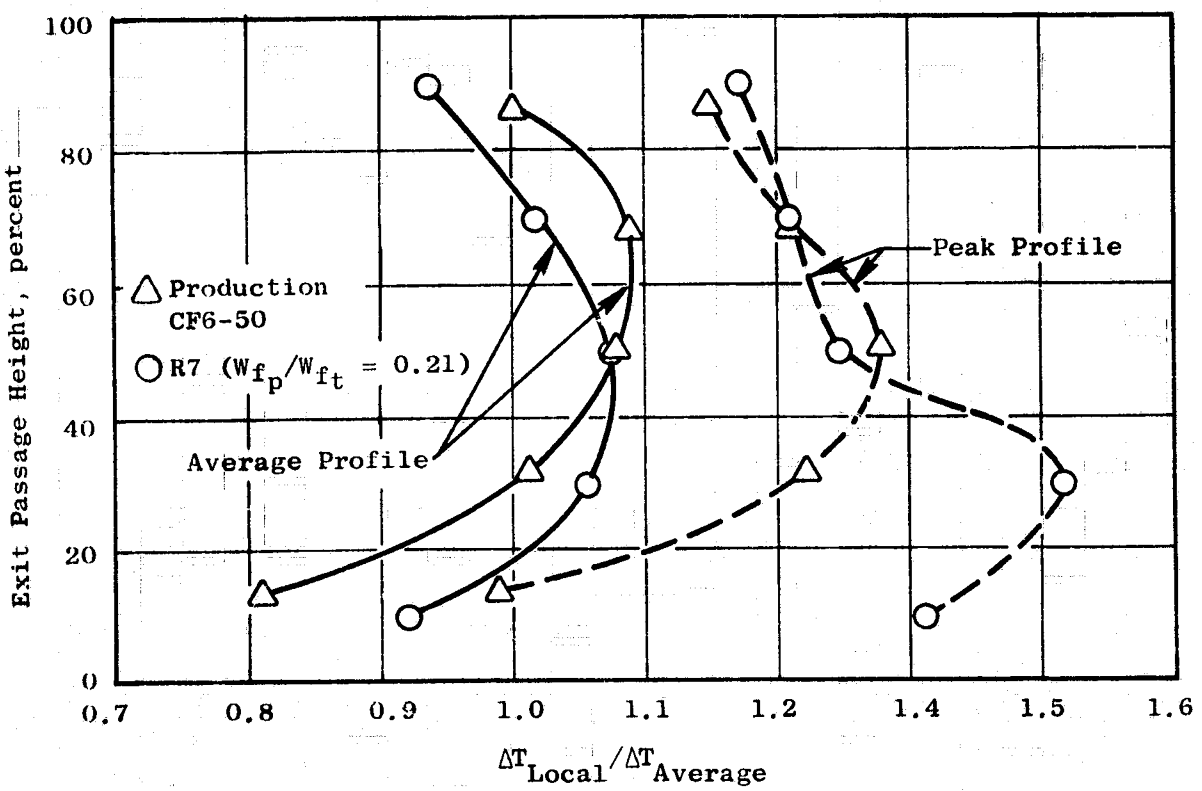

Figure 46. Exit Temperature Profile Characteristics of Final Radial/Axial Staged Combustor Configuration.

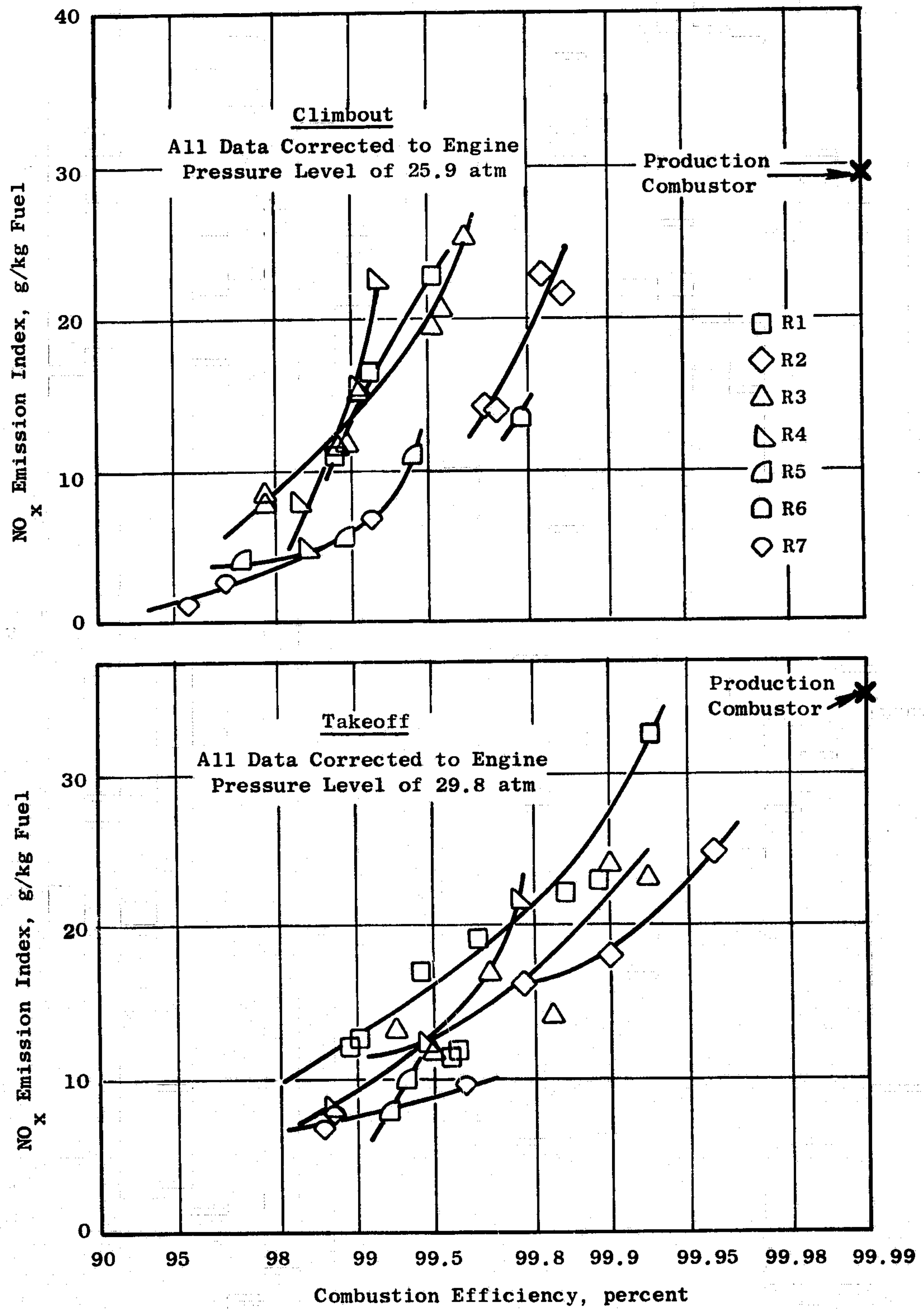

Figure 47. Tradeoff Between Combustion Efficiency and NO_x Emission Levels at Climbout and Takeoff Operating Conditions for the Radial/Axial Staged Combustor.

CO, HC, and NO_x EPA parameters of 5.4, 0.1 and 4.3 could be obtained. An alternate fuel split at climbout and takeoff would reduce the CO EPA parameter to 4.4, but the NO_x EPA parameter would climb to 5.9.

Since development of this combustor design was stopped midway through Phase II in favor of the Double Annular Combustor, no single configuration met all of the performance requirements. The pilot stage swirl cup design, which operated carbon-free and met the altitude relight requirements in the Double Annular Combustor, was not tested in the Radial/Axial Staged Combustor. However, based on the results obtained in the Double Annular Combustor tests and in the Radial/Axial Staged Combustor sector tests, it is expected that the altitude relight and carbon-free requirements could be met with this combustor with a small amount of further development and with little or no impact on the emission levels. More development effort would be required, however, to eliminate the main stage flashback tendencies encountered.

CHAPTER IV

ASSESSMENT OF PHASE II TEST RESULTS

COMMON RESULTS

Both of the Phase II combustor design concepts proved capable of providing large emission reductions, relative to the production CF6-50 combustor, while meeting or closely approaching most performance goals required for engine application. The design features responsible for the reduced levels of CO, HC, and NO_x were very similar for the two combustors and are the significant features which appear necessary in any combustor design to obtain low NO_x emission levels, as well as low CO and HC emission levels.

Both the Double Annular and the Radial/Axial Staged Combustors consist of two-stage designs, wherein the first (pilot) stage operates alone at low engine power operating conditions and both stages (pilot and main) operate together at high engine power operating conditions. The pilot stage of both combustors was designed to utilize only a small fraction of the combustor airflow (15-20%). The sheltered, low velocity pilot dome region produced low idle CO and HC emission levels and excellent altitude and sea level ignition characteristics. Good fuel atomization and careful introduction of the fuel-air mixture into the pilot combustion zone to avoid wall quenching effects were found to be important design features. In addition, the inclusion of many small dilution holes in the pilot stage primary zone region proved to be essential for reducing the CO emission levels to the degree required.

The main stage of each compressor is supplied with a significant proportion of the total combustor airflow (40-60%) to provide a lean, high velocity combustion zone in order to minimize the formation of NO_x at the high power operating conditions. In each combustor design concept, most of the fuel flow (75-85%) is supplied to the main stage at takeoff conditions. In the Radial/Axial Staged Combustor, the main stage airflow is carbureted in a premixing passage before combustion and ignited by the piloting action of the first stage. In the Double Annular Combustor, about three-fourths of the main stage airflow is supplied to the swirl cups and one-fourth is supplied to large dilution holes designed to quench the NO_x reactions. This design was found to be more favorable than supplying all of the main stage airflow to the swirl cups due to improvements in the main stage ignition and stability characteristics and elimination of resonance tendencies. From the investigations undertaken in Phase II, it appears that each combustor must be operated on only its pilot stage from lightoff to a power setting above the EPA-defined approach condition (30% power), in order to obtain acceptable low CO and HC EPA parameters. The main stage can preferably be cut in slightly above approach power and remain on for the rest of the operating range.

DOUBLE ANNULAR COMBUSTOR RESULTS

The performance and emissions development status of the Double Annular Combustor is summarized in Table XXIV.

Table XXIV. Phase II Development Status of the Double Annular Combustor.

	Current Status		
Parameter	Meets Requirements	Further Refinement Needed	Significant Further Development Required
• Emissions			
- CO	X		
- HC	X		
- NO_x			X
- Smoke	X		
• Ground Starting	X		
• Altitude Relight	X		
• Lean Blowout - At Idle	X		
• Main Stage Cross-Firing	X		
• Pressure Loss	X		
• Combustion Efficiency	X		
• Exit Temperature Profile/ Pattern		X	
• Resonance	X		
• Flashback	X		
• Carboning	X		
• Metal Temperatures	X		

Pollution Status

The CO and HC emission levels of this combustor are very low at all operating conditions and the 1979 EPA standards were met in the component tests. The smoke levels were also below the applicable standard, but the NO_x levels remain about 50% above the 1979 standard. NO_x reductions of about 45 percent were achieved, compared to the production CF6-50 combustor, with essentially no loss in combustion efficiency.

Based on the Phase II test results, the Double Annular Combustor can operate at cruise conditions with both stages burning at the fuel split which produces the lowest NO_x levels, with combustion efficiencies greater than 99.8%. At the approach mode, however, it appears that pilot stage only operation is required to obtain the high combustion efficiency (and corresponding low CO and HC levels) demanded by the EPA landing-takeoff cycle. The effect of fueling both stages at approach will be investigated further in the Phase III engine demonstration tests.

Performance Status

The Double Annular Combustor met all of the performance requirements during Phase II, as shown in Table XXIV. However, no attempt was made to trim the exit temperature peak profile during Phase II. This will be done with the engine demonstrator combustor during the Phase III component testing prior to the engine buildup. For this reason, the exit temperature profile/pattern is indicated as "further refinement needed" in Table XXIV. The control of exit temperature profiles is much more difficult with the Double Annular Combustor than with conventional single annular combustors, because much less of the total combustor airflow is available for introduction as dilution air through holes in the cooling liners. However, the development engine exit temperature profile requirements at takeoff are expected to be attained during the Phase III component tests. The cross-firing characteristics of this combustor will be under close scrutiny during Phase III in order to determine the impact on engine acceleration/deceleration performance. The Phase II cross-fire tests were conducted in a quasi-steady-state manner with no attempt made to simulate the transient pressure and temperature conditions encountered in the engine operation as the main stage is cut in. From these component test results, it is felt that the cross-fire performance will prove satisfactory during Phase III. Nonetheless, some questions do exist which can only be answered by actual engine tests.

RADIAL/AXIAL STAGED COMBUSTOR RESULTS

The performance and emissions development status of the Radial/Axial Staged Combustor at the conclusion of the Phase II program is summarized in Table XXV.

Table XXV. Phase II Development Status of the Radial/Axial Staged Combustor.

Parameter	Current Status: Meets Requirements	Current Status: Further Refinement Needed	Current Status: Significant Further Development Required
• Emissions			
– CO			X (Various Tradeoffs Possible)
– HC	X		
– NO_x			X (Various Tradeoffs Possible)
– Smoke	X		
• Ground Starting	X*		
• Altitude Relight	X		
• Lean Blowout - At Idle	X		
• Main Stage Cross-Firing	X		
• Pressure Loss	X		
• Combustion Efficiency			X
• Exit Temperature Profile/ Pattern		X	
• Resonance	X		
• Flashback			X
• Carboning	X*		
• Metal Temperatures	X		

*Expected to meet based on sector tests and Double Annular Combustor development test results.

Pollution Status

Various configurations of this combustor met the HC, NO_x and efficiency goals of the ECCP Program and very closely approached the CO goal. This combustor was found to be more sensitive to changes in the combustor inlet conditions and the fuel split between stages than the Double Annular Combustor. A direct tradeoff was found to exist between NO_x and combustion efficiency when both stages are fueled. From a fuel utilization standpoint, combustion efficiencies of 98 or 99% are tolerable at takeoff and climbout

due to the small amount of time spent at these modes and the resulting small impact on the overall fuel economy performance of the engine. In order to meet the 1979 EPA CO and HC standards, however, combustion efficiencies of greater than 99.8% are mandatory. To increase the high power efficiency of the Radial/Axial Staged Combustor from 99% to 99.8%, requires a fuel flow split and main stage airflow design change at takeoff and climbout which increases the NO_x level more than 100%. The resulting NO_x levels are then comparable to or higher than those of the Double Annular Combustor.

At cruise conditions, the combustion efficiency must be 99.8% or higher because of the impact on the overall engine fuel economy. Because of the combustor inlet pressure and temperature at the cruise condition, pilot-stage-only operation may be required with the Radial/Axial Staged Combustor to achieve the required efficiency level. If this is the case, NO_x levels only slightly lower than those of the production combustor would be expected (Figure 40). As with the Double Annular Combustor, pilot-stage-only operation at approach appears to be the only feasible fueling mode in order to meet the EPA standards.

Further development efforts are required to improve the combustion efficiency levels of the Radial/Axial Staged Combustor at high power operating conditions, while simultaneously maintaining the low NO_x levels demonstrated in Phase II. These efforts should probably incorporate somewhat lower main stage airflow levels and improved main stage premixing features to more carefully control the stoichiometry of the main stage mixture. Further, it appears that a longer combustion zone, downstream of the flameholder array, is required to allow more residence time for CO and HC consumption to occur. Gas temperatures in this zone are high enough to allow further CO and HC consumption, but low enough to limit further NO_x formation. Therefore, the increased length would be expected to significantly increase the overall combustion efficiency, with only a small impact on the NO_x level of the combustor.

Performance Status

The Radial/Axial Staged Combustor met most of the performance requirements during Phase II. However, flame flashback into the main stage premixing passage was encountered with two annular test configurations. In the Phase II development efforts, it was evident that no trouble would be encountered in meeting the ground starting, altitude relight and carboning requirements with the additional Phase II development efforts afforded the Double Annular Combustor. The performance problems which were found to be the most troublesome with the Double Annular Combustor - main stage ignition, exit temperature profile control and resonance - were not encountered at all with the Radial/Axial Staged Combustor. The exit temperature parameter shown in Table XXV is indicated "further refinement needed" since further adjustments to the peak profile would be required before incorporation in an engine. However, "significant further development" is required to eliminate the flashback tendencies of the main stage of this combustor.

These further development efforts should emphasize the aerodynamic features of the premixing passage to avoid any features which may tend to trigger flashback. Any potential low velocity regions, such as those arising from wakes behind fuel tubes, protruding bolts or other surface disruptions must be eliminated. The potential for flashback would also be greatly reduced, in a lower pressure ratio cycle due to the lower combustor inlet temperatures.

APPLICATION OF RESULTS

Phase III Engine-Combustor Selection

Both the Double Annular Combustor and the Radial/Axial Staged Combustor demonstrated strong points and weak points during their development. In the final assessment, however, it was the overall excellent performance and lower CO and HC emission levels of the Double Annular Combustor, and the more conventional dome design concept involved, weighed against the flashback concerns of the Radial/Axial Staged Combustor, and the severe compromise in NO_x characteristics required to obtain the necessary high efficiencies that led to selection of the Double Annular Combustor design for further development effort and demonstration in the Phase III Program.

Phase III Engine-Combustor Testing

While significantly reduced pollutant emissions and promising performance characteristics have been obtained in the component tests of the Double Annular Combustor, it must be recognized that this advanced combustor is considerably more complex than current technology combustors. Although the combustor has been developed to the point of demonstration in an engine, several potential problem areas must be addressed and resolved before it can be incorporated into operational engines. Many of these problem areas are engine related and therefore, could not be adequately evaluated in the Phase II combustor component tests alone. A number of these areas will be investigated in the Phase III engine tests. Others, however, are beyond the scope of the Experimental Clean Combustor Program.

One of the important unknowns with a staged combustor is the transient operating characteristics of the engine during acceleration and deceleration operations. Combustion staging, which involves cross-firing between stages during acceleration operations in the case of the Double Annular Combustor, must proceed smoothly and rapidly. Because of the additional required features in the fuel control and supply systems and the need for ignition of one combustor stage by another stage, the attainment of smooth and adequately rapid engine acceleration characteristics with this advanced combustor is a much more formidable development problem than with current technology combustors. Similar development problems must be anticipated in meeting deceleration performance requirements.

At present, the transient performance characteristics of the Double Annular Combustor are not well established since it is not possible to obtain an adequate evaluation in component tests. Therefore, an important part of the Phase III demonstrator engine investigations will be devoted to assessments of the engine acceleration/deceleration characteristics.

Possible fuel nozzle carboning at engine power settings where the main stage is shut off after being in operation is another development concern. This area was not a problem during the component tests because purge air was used to evacuate the residual fuel from the fuel system whenever the main stage fuel flow was shut off. The main stage nozzle used in the component tests had a smaller orifice size than the engine nozzles because of the lower fuel flows required in the reduced pressure component tests. Accordingly, the use of purge air was necessary to prevent plugging of the nozzle orifices. In the engine, provisions for purging the main stage nozzles are not available.

Another area of possible concern with regard to engine application is the highly peaked exit temperature profiles at the low power operating conditions, when only the pilot stage is fueled. At steady state low power operating conditions, peaked profiles are expected to be tolerable. However, during low power thrust transients, excessive exit temperatures may result for brief time periods and may affect the cyclic life characteristics of the turbine components of the engine.

The significant impacts on the fuel control and supply systems of engines which result from the use of multi-stage combustor design concepts are another area of concern. Much additional complexity and sophistication must be added to the fuel control and supply systems to permit the use of these advanced combustors. Provisions for accurately dividing the total fuel flow into the proper proportions required in each combustor stage, at all engine operating conditions, are needed in the fuel control system. To meet this need, complex logic and fuel flow valving equipment is required to accommodate the wide ranges of total fuel flows and required fuel flow splits associated with engine operation at both ground level and cruise conditions. At cruise conditions, for example, most of the fuel is supplied to the main stage. The total fuel flows at these cruise conditions are similar in magnitude to those at low power settings at sea level. However, at these low power sea level conditions, all of the fuel must be supplied to the pilot stage. A prototype add-on fuel control system mechanism of this kind for sea level operation has been designed for use in the Phase III CF6-50 engine tests. The development and demonstration of fully operational versions of these required new fuel control system features suitable for both sea level and altitude operation will involve significant further effort.

Following the completion of the Phase III investigations, it is expected that the magnitude of several of the presently identified development concerns associated with the engine application of the Double Annular Combustor design concept will be much better defined and that means of resolving these concerns will be identified. It is expected that additional

combustor component and engine development efforts will be needed following these Phase III investigations to develop and implement any needed improvements.

Thus, the Double Annular Combustor design concept appears to offer considerable promise as a means of obtaining significant reductions in pollutant emission levels, relative to current combustors, without incurring significant compromises or losses in other key combustor performance and operational capabilities. The key emission reduction design features have been identified in the development tests of Phase I and Phase II, and implemented into the final design configuration for Phase III. Prototype versions of this final design, tested during Phase II, demonstrated these significant emission reductions while meeting essentially all of the combustor performance requirements specified for engine operation. Some further development concerns with this combustor, primarily engine-related operating characteristics, have been identified. The magnitude of these concerns should be much better defined following the Phase III Program. After the completion of the Phase III Program, therefore, it is anticipated that it will be possible to specify, in detail, the needed additional design improvements, needed further development efforts and needed development time schedules required to permit the use of this new and advanced combustor design technology in operational engines.

CHAPTER V

PHASE II - ENGINE-COMBUSTOR DESIGN ITEMS

In addition to the combustor testing and evaluations described in Chapters III and IV, Phase II also included several concurrent design efforts. These consisted of mechanical design of engine-combustor hardware for the Double Annular and the Radial/Axial Staged Combustor concepts suitable for installation in the CF6-50 engine, resolution of interface problems associated with engine installation and design of a breadboard engine fuel control system design capable of controlling fuel flows for either multi-stage combustor.

ENGINE COMBUSTOR DESIGNS

Engine combustor design efforts were initiated using the aerothermal results of the Phase I Program. The inputs to both designs were continually revised as test results became available. At the completion of Radial/Axial Staged Combustor testing, design efforts on this design were terminated. The Double Annular design effort was carried through to completion of an engine-combustor design.

The mechanical designs of the two combustor concepts were configured to fit into the current production CF6-50 engine with a minimum change in current engine hardware. The swirl cup, venturi and the swirler arrays for the pilot stages of both combustor concepts are identical. The mechanical attachment of the swirl cups to the dome is likewise similar for both designs. Although the cooling liners are not common, due to the flowpath considerations, both combustors employ the same advanced machined cooling ring concept. This new combustion liner design gives added mechanical stiffness while maintaining a high film cooling effectiveness.

Both combustors are designed to provide a minimum of 100 hours of life at the maximum temperature and stress condition. The minimum low cycle fatigue life is calculated to be at least 300 cycles with a calculated high cycle fatigue capability in excess of 10^6 cycles. Table III shows the design conditions used for the mechanical analysis of both combustors.

Double Annular Combustor

The engine combustor design incorporates the key design features and optimum flow distribution determined by the development tests, and duplicates Double Annular Combustor Configuration D12 to as large an extent as possible.

The key design features are:

1. Pilot and main stage secondary swirler mixing barrels
2. Pilot and main stage pressure-atomizing nozzles
3. Pilot and main stage dilution
4. Short centerbody
5. Cross-fire slot

The flow distribution of the demonstrator engine test configuration together with the key combustor design velocities are shown in Table XXVI. For comparison, similar information for Configuration D12 is also shown. Minor differences are due to the higher cooling flows required for the engine demonstrator.

Figure 48 shows the design layout of the Double Annular Combustor. The combustor is structurally supported at the forward end by 30 pins as is the production CF6-50 combustor. The combustor is allowed to slip radially on the pins and axially at the aft end through fishmouth seals. The inner and outer domes, centerbody and liners are supported through the cowl, and all of the individual structures are bolted to the cowl for easy maintainability or replaceability.

The cowl consists of three flow guides which are supported through 30 radial struts. The flow guides serve the dual purpose of dividing the compressor discharge flow and providing a continuous structure for bolting the individual components. The struts provide the path for the mechanical loads from the liners, dome and centerbody to be transmitted to the engine casing. Thirty pin mounts are located on the upper cowl surface. The pin mounts and the radial struts are aerodynamically streamlined to minimize the pressure drop across them. The struts and cowl flow guides are designed to maintain an axial stiffness comparable to the current CF6-50 combustor cowl. The cowl is fabricated from Hastelloy-X sheet and bar stock. The individual flow guides are rolled, welded and spun sheets. The 30 radial struts and the pin supports are welded in place.

There are 30 swirl cups in each of the inner and outer domes. The swirl cups are integral assemblies which are mechanically fastened to the dome through radial slip joints. The cups slip radially relative to the dome assembly, permitting the differential thermal expansion during transients and the mechanical stack-up between the dome assemblies, fuel nozzles and casing to be alleviated. The dome structures are made from Hastelloy-X material. On the hot side of the structures, the thermal loads are borne by splash plates attached to each swirl cup. These splash plates are exposed to the extremely hot combustion gases, and shield the dome structures from excessive temperatures. These splash plates are impingement-cooled by holes located in the dome structures.

Table XXVI. Double Annular CF6-50 Combustor Design for Phase III Engine Tests.

Airflow Distribution ($\%W_C$)	Demonstrator Engine Design Configuration	Phase II Prototype (D12) Configuration
• Outer dome		
Swirlers	12.6	13.4
Dilution (from second liner panel)	4.5	4.7
Cooling	7.2	4.5
• Inner dome		
Swirlers	33.0	33.1
Dilution (from first liner panel)	10.6	10.8
Cooling	5.4	4.1
• Centerbody	3.1	3.9
• Inner liner dilution (trim air)	2.0	4.8
• Liner cooling	20.2	19.2
• Aft seal	1.4	1.5
	100.0	100.0
Key Velocities		
Outer dome (m/s)	10	11
Inner dome (m/s)	29	29
Outer passage (m/s)	37	24
Inner passage (m/s)	46	59
Reference (m/s)	23	26

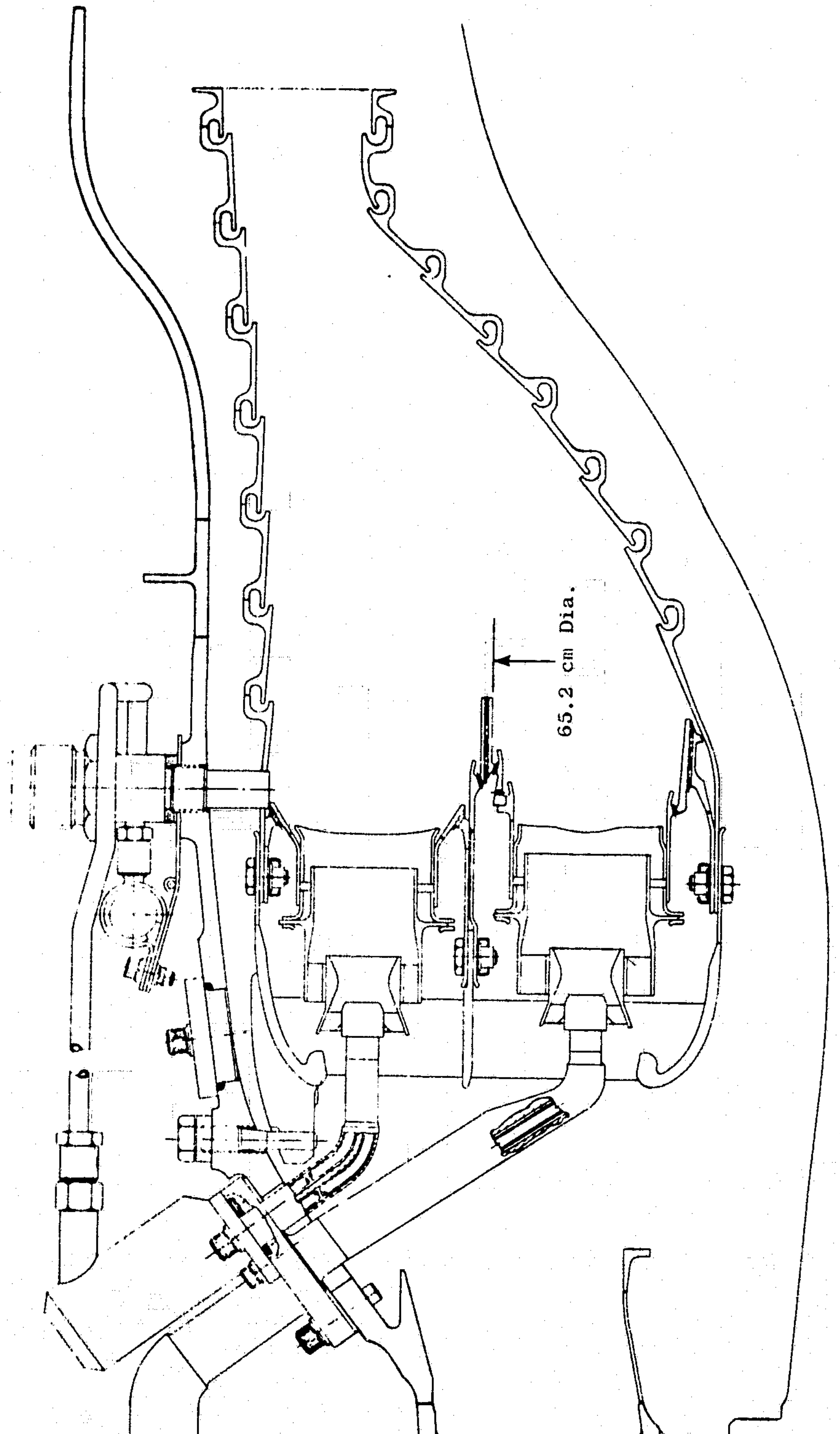

Figure 48. Double Annular CF6-50 Combustor Design.

The Double Annular Combustor design incorporates 60 fuel nozzles, 30 for both the inner and outer dome. The nozzles have been designed to allow the utilization of the 30 fuel nozzle ports which currently exist on the CF6-50 compressor rear frame. With this design, both sets of fuel nozzles can be inserted or removed with the combustor installed in the engine for easy maintainability. The assembly sequence for the nozzles is shown in the series of pictures of Figure 49. Both sets of fuel nozzles are designed with natural vibratory frequencies above the range of current engine frequencies in order to prevent possible resonant interactions. The nozzle cross sections are aerodynamically contoured to minimize losses and reduce aerodynamic loads on them.

The fuel distribution valve for each fuel nozzle is mounted outside the combustor casing above the nozzle support plate. With a conventional single annular combustor, the constantly-flowing fuel is used as a heat sink to protect the valves from overtemperature. With the Double Annular Combustor, however, the inner dome fuel nozzles will not be fueled at low or intermediate power operating conditions. Therefore, the distribution valves are set away from the casing somewhat in order to minimize thermal soaking (and possible damage) of the valves.

The inner dome fuel nozzles incorporate a simplex orifice design. In order to provide adequate protection against carbon formation or gumming of the residual fuel within the fuel tube when the fuel is shut off to the inner dome, a false wall construction is used. A tube is placed within the inner nozzle structure surrounding the fuel-carrying tube, in order to insulate the fuel tube from the hot compressor discharge temperature airflow. The outer dome fuel nozzles are duplex orifice nozzles in order to ensure good fuel atomization over the range of starting and steady-state fuel flow required. The existing CF6-50 engine fuel manifold and pigtails will be used to fuel the inner dome nozzles. A separate, newly-constructed fuel manifold will be required to supply the outer dome nozzles.

The outer and inner dome regions are physically isolated by the combustor centerbody. The centerbody is a machined ring structure whose outer portion is bolted to the center flow guide of the cowl. The inner portion of the centerbody is not bolted but is allowed to slip, relative to the inner dome, to allow axial and radial thermal growth without resulting mechanical distortion. The upstream panels of the centerbody are cooled by film-cooling holes, while the aft panel is also cooled with long convective holes.

The axial locations of the centerbody cooling rings were selected to minimize the temperature gradients of the aft panel between the inner and outer diameters. This is essential to the mechanical integrity of the centerbody. During various engine operating conditions, the inner and outer dome gas temperatures and heat transfer coefficients are different, thereby inducing a thermal gradient across the centerbody. In order to minimize this gradient, the inner ring was positioned further aft, thereby providing a higher film cooling effectiveness to this surface.

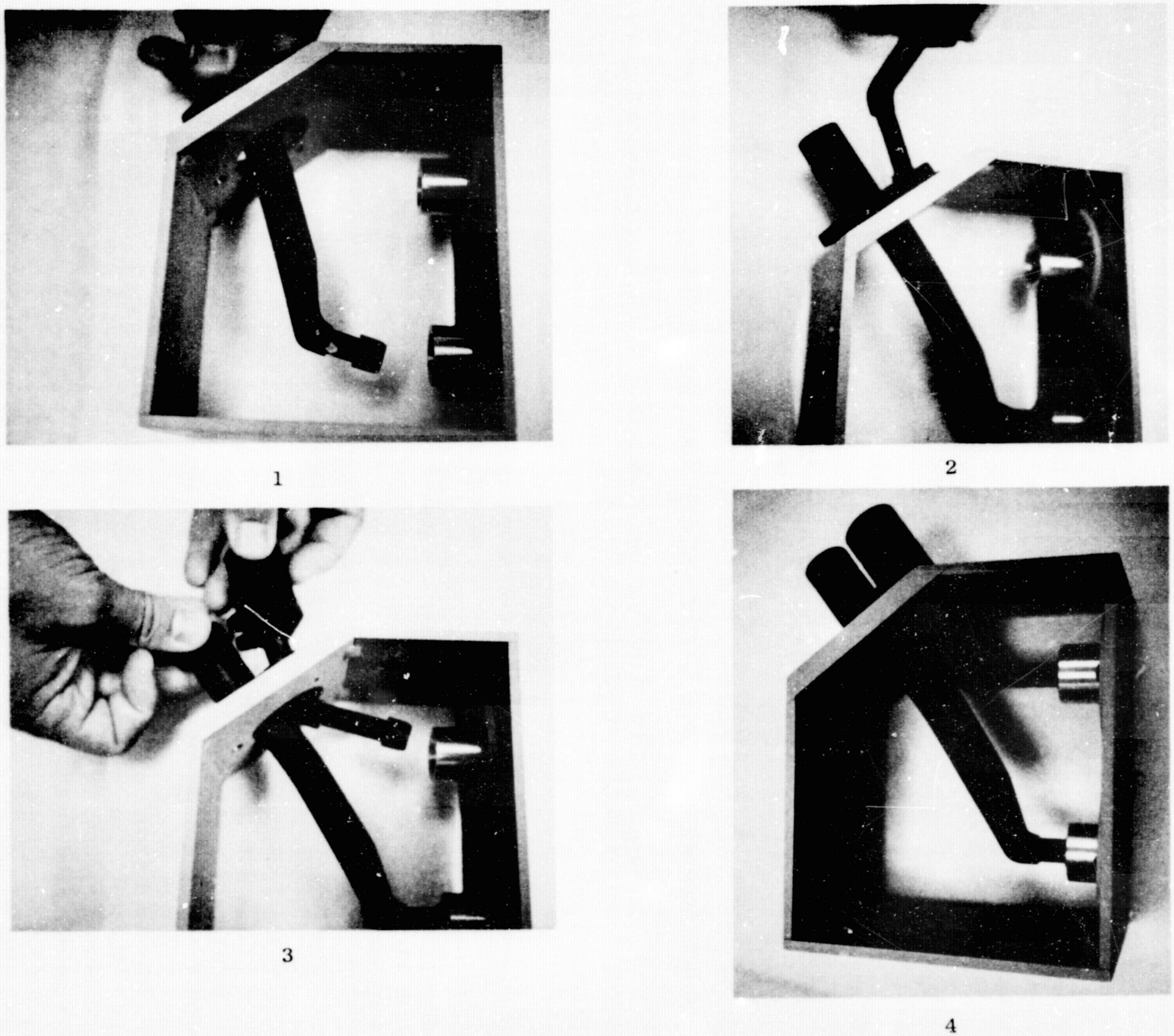

Figure 49. Fuel Nozzle Installation Sequence, Double Annular Combustor.

The combustion liners are made from HS 188, a cobalt based alloy. Each film slot is fabricated from a machined ring, which is electron-beam welded together at the top of the film-cooling slot plenum. This design yields a high degree of film-cooling effectiveness while providing mechanical stiffness greater than the current CF6-50 stacked ring configuration. The increased mechanical stiffness provides greater resistance to creep buckling. Air enters through electrical discharge machined (EDM) holes. The air washes the ring, thereby convectively cooling it and then exists as a continuous film, providing protection for the structural wall. This approach is used on the inner and outer liners of both the Double Annular and Radial/Axial Staged designs.

Radial/Axial Staged Combustor

The engine combustor design incorporates the key design features determined by development tests. These key features are:

1. Pressure-Atomizing nozzles in the pilot stage
2. Pilot stage dilution
3. Reduced main stage carbureted airflow
4. Increased number of main stage flameholders (and, hence, increased active perimeter for flamespreading)
5. Radial main stage fuel staging at intermediate power settings.

The flow distribution of the demonstrator engine test configuration together with the key combustor design velocities are shown in Table XXVII. The main stage premix velocity is very important, since it is a key parameter in main stage flashback and/or pre-ignition. This velocity has been set at a higher value in the engine demonstrator than in Configuration R7 in order to better assure that flashback or pre-ignition will not occur.

The Radial/Axial Staged Combustor design layout is shown in Figure 50. The combustor consists of six basic sub-assemblies which are bolted together to form the combustor assembly. They are the cowl, dome, chute, splitter, outer liner, and inner liner. The combustor is supported at two places on the compressor rear frame casing. The cowl, dome, and inner liner are supported by pins engaged in struts on the splitter.

The main structural cowl supports the inner liner and the pilot stage dome. The cowl consists of two flow guides, which are supported by 30 airfoil shaped struts. The inner liner and dome are bolted to the cowl inner flow guide. The upper portion of the dome is bolted to the outer cowl flow guide through a structure which allows air to enter the forward outer liner while providing a means to mechanically attach the structure to the cowl. The cowl is attached to the combustor outer casing by 30 pins in a similar fashion to the production CF6-50 and the Double Annular Combustor designs.

Table XXVII. Radial/Axial Staged CF6-50 Combustor Design For Phase III Engine Tests.

Airflow Distribution (%W_c)	Demonstrator Engine Design Configuration	Phase II Prototype (R7) Configuration
• Pilot stage		
Swirlers	12.2	15.8
Dilution (from liners)	4.5	5.6
Cooling	11.1	11.3
• Main stage	50.0	47.2
• Liner dilution (trim air)	2.0	0
• Liner cooling	17.4	16.9
• Main stage flameholder cooling	1.4	1.6
• Aft seal	1.4	1.6
	100.0	100.0

Key Velocities		
• Pilot dome (m/s)	13	15
• Main stage premix (m/s)	75	57

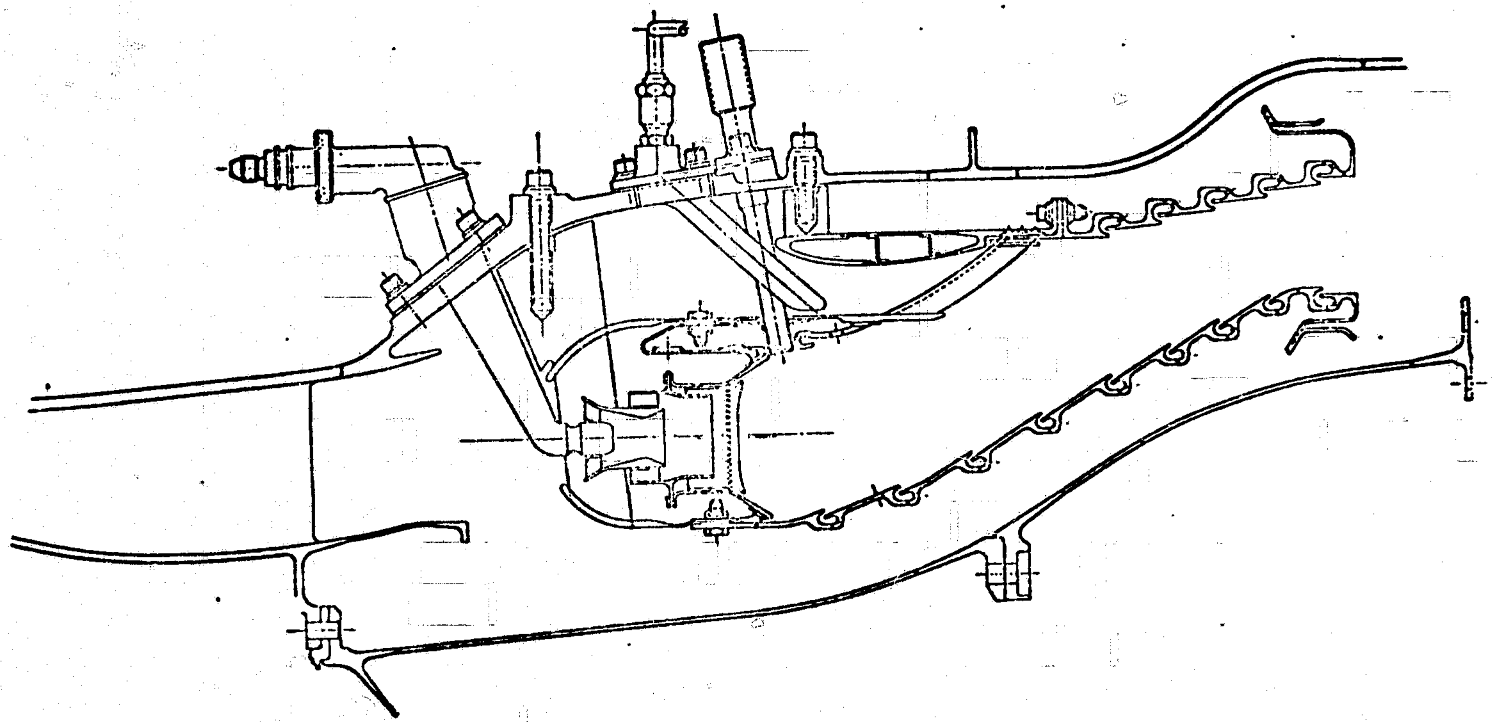

Figure 50. Radial/Axial Staged CF6-50 Combustor Design.

The pins allow radial movement of the cowl, relative to the dome, thereby relieving any potential thermal stress during transient or off-design operation. The entire assembly would be made from Hastelloy-X sheet and bar stock.

The Radial/Axial Staged combustor pilot stage is identical in concept to the outer dome of the Double Annular Combustor. The dome consists of 30 swirl cups mechanically held in a dome plate. The dome plate is formed by individual plates, butt-welded together to form a continuous ring. Machined cooling rings are welded to the end of the plate to cool the dome/liner interface joint. The structural plate is protected from the hot combustion gases by individual splash plates. The structural plate has impingement holes drilled in it, for impingement cooling the splash plates.

Two holes are required in the structure between the pilot dome and the main stage premixing passage to allow insertion of the igniters. The outer hole has a floating ferrule to effect a seal between the outer flowpath and film supply cavity, therefore avoiding cross flow from the main stage flow passage. The inner hole is sized to permit sufficient axial thermal growth of the combustor.

The main stage flameholder assembly would be fabricated of Hastelloy-X cast chutes welded to outer and inner Hastelloy-X sheet bands. The outer band is a double layer construction with holes in the outer layer. This permits cooling air to pass through the outer layer, impinge on and cool the inner layer. The inner layer requires cooling due to hot gases impinging on the inside after passing along the aft side of the chutes. The inner shell of the flameholder assembly interfaces with the pilot dome/cowl structure with "fish-mouth" type joints which provide radial restraint but allow relative axial motion. This eliminates unnecessary redundancy and minimizes thermal stresses.

The chute assembly is supported through the splitter. The forward and aft outer combustor liner mechanical loads pass through the chute assembly into the splitter where they are passed into the outer combustor case through 20 support pins. The splitter forms the converging-diverging flowpath for the chute assembly. It also isolates the aft outer liner cooling flow from the main stage combustion air. The splitter would be fabricated from Inco 718, a nickel based alloy. The flange, which supports the chute and outer liner, is scalloped to minimize thermal stress and blockage of the flow around the outside of the combustor.

The Radial/Axial Staged Combustor design incorporates 30 conventional duplex fuel nozzles in the pilot stage and 60 spray bar injectors in the main stage. The pilot stage nozzles are inserted through the existing 30 fuel nozzle ports of the CF6-50 engine casing. The main stage injectors would require additional ports to be added to the casing. The pilot stage nozzles are supplied from the existing CF6-50 engine fuel manifold. A separate, newly-constructed fuel manifold would be required to supply the main stage injectors.

The CF6-50 compressor rear frame would require modification to accommodate the main stage fuel system and new ignitor location. The mounting provisions for the pilot stage fuel nozzles and forward support pins are the same as in the production CF6-50 configuration.

Engine Combustor Interfacing

Both combustors have been designed to fit into the current production CF6-50 engine with a minimum change in current engine hardware. Interfaces with the current turbine stator and compressor rear frame are identical in both designs to those of the production design. However, several modifications to existing CF6-50 hardware are required by the two combustors. Requirements for both combustors are summarized in Table XXVIII.

Table XXVIII. Engine/Combustor Interfacing Requirements.

Double Annular Combustor

- New inner structural turbine nozzle support to accommodate increased height of the Double Annular Combustor (i.e., a new inner casing).
- A second fuel manifold for the pilot stage nozzles.
- An add-on fuel flow splitter control.

Radial/Axial Staged Combustor

- Outer casing modification to accommodate the 60 main stage fuel injector assemblies, mounting pins for the outer liner and chute assembly, and new ignitor locations.
- A second fuel manifold for the main stage fuel injectors.
- An add-on fuel flow splitter control.

For the Double Annular Combustor design, the inner structural turbine nozzle support (inner casing) had to be changed to accommodate the increased height of the Double Annular Combustor dome. In addition, a second fuel manifold was provided for the 30 pilot stage duplex nozzles. This permits the outer (pilot) dome to be fueled at the low power flight mode without fuel flow to the inner dome. This is an essential feature of the fuel scheduling and will be discussed in a later section of this chapter. Both combustor designs utilize an add-on fuel flow splitter control to achieve fuel staging.

For the Radial/Axial Staged Combustor design, the outer combustor casing requires modification to accommodate the main stage fuel injection system, and to provide a mounting point for the outer liner and chute assembly. This modification to the casing was confined to one of the cast sections. Since the main stage fuel injectors penetrate the casing aft of the existing fuel ports an additional fuel manifold is required to supply fuel to these injectors. This permits separate fueling of the pilot and main stages. As with the Double Annular Combustor, an add-on fuel flow splitter control is required.

ENGINE FUEL CONTROL DESIGN

The engine fuel control system is the means by which the fuel staging requirements of either combustor will be implemented in the engine tests. Initial studies were applicable to either combustor design. After the selection of the Double Annular Combustor as the preferred combustor design, all further design efforts were directed toward this concept.

In either design, to most closely approach the 1979 EPA emission standards, particular fuel flow splits between stages at the four EPA-defined test conditions have been identified from Phase I and II testing efforts. Test data obtained to date indicate that the best fuel schedule for the sea level static engine operating line, from an emissions standpoint, is to:

1. Fuel only the pilot stage at the idle and approach operating conditions.

2. Split the fuel flow at climbout and takeoff so that about 15 to 25 percent of the total fuel flow is supplied to the pilot stage, and the remainder to the main stage.

The add-on fuel flow splitter design concept for the Phase III demonstration tests is shown in Figure 51. The main engine fuel control (MEC) supplies the engine fuel flow required by the throttle setting. The add-on flow splitter then splits the fuel flow between the pilot stage manifold and the main stage manifold. The flow splitter has two adjustable settings. The main stage cut-in point, and the pilot-to-total fuel flow split after cut in. The design requirements of the combustor determine the levels of the adjustable settings in the flow splitter. The design requirements are shown by the curve in Figure 51. The pilot stage alone is fueled from ground idle to a preset cut-in point, the main stage fuel flow is initiated, and the pilot stage flow is rapidly decreased. At the 40 percent thrust operating condition, typically about 20 percent of the fuel is supplied to the pilot stage and 80 percent is supplied to the main stage. This fuel flow split is maintained until 85 percent thrust, and then transitions to about 15 percent pilot stage flow. The cross-hatched region in Figure 51 indicates the general range in which the preferred fuel splits are expected to be found.

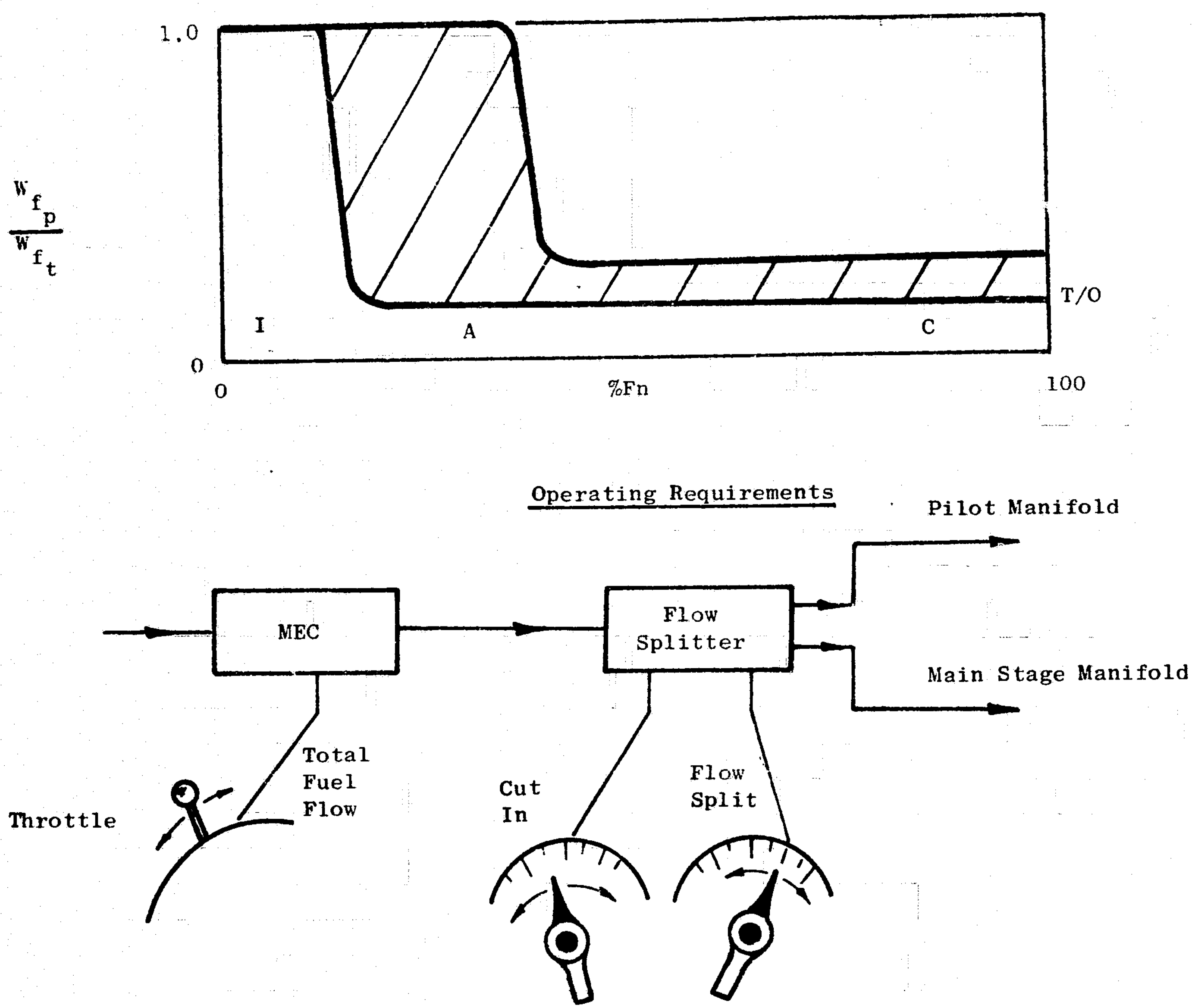

Figure 51. Add-on Fuel Flow Splitter Design Concept.

A fuel flow splitter component design has been developed in Phase II which closely approaches the desired fuel flow schedule and is compatible with the current CF6-50 main engine fuel control system. A schematic of the fuel flow divider component design is shown in Figure 52. Although a nominal fuel schedule has been selected for the sea level engine operating line from Phase I and Phase II testing, an important part of the Phase III program will be to determine the preferred fuel flow scheduling. The design shown in Figure 52 will allow the fuel flow split between stages of the combustor to be varied at approach and at any operating condition above the programmed cut-in point of the main stage. The main stage cut-in point can also be varied with this design. These adjustments will be made from the test cell control room during engine operation.

DESIGN STATUS OF COMBUSTOR FOR PHASE III PROGRAM

The Double Annular Combustor is currently being manufactured for further evaluation during Phase III. As of the end of Phase II, the mechanical design of the Double Annular Combustor is complete. All of the important design features identified in the testing efforts have been included in the design. Detailed manufacturing drawings have been prepared for the required combustor hardware and manufacturing orders have been placed. Delivery of all combustor hardware is expected by January 1976.

The design of the engine fuel nozzles and add-on fuel flow splitter is also complete and delivery of this hardware is expected during January 1976. Prior to the engine demonstration testing scheduled for the second quarter of 1976, the fuel splitter will undergo laboratory checkout tests to verify its performance characteristics. The hardware required for these bench tests has been fabricated and set up is nearing completion.

Some slight modifications to the full annular test rig have been identified to allow component checkout tests of the engine combustor prior to engine installation. These modifications principally include recontouring of the inner combustor casing to allow for the increased dome height of the engine combustor, compared to the Phase II development combustor. These modifications have been completed.

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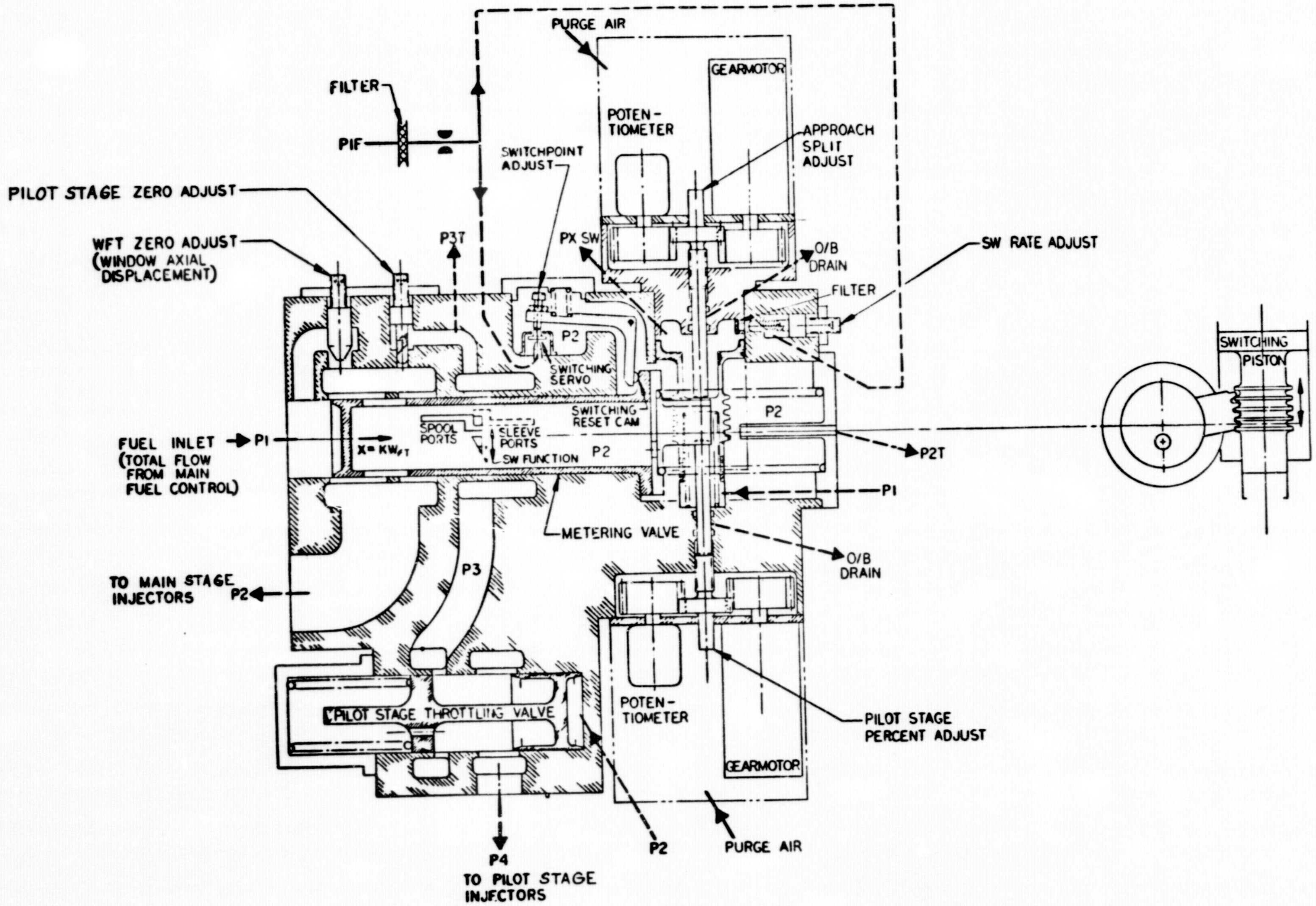

Figure 52. Add-on Fuel Flow Splitter.

APPENDIX A

EMISSIONS CORRECTION FACTORS

This appendix presents factors which were established in the Phase II Program to correct test rig emission data to engine operating conditions. Generally, combustor inlet temperature, reference velocity and fuel-air ratio were exactly duplicated in the test rig, but at approach, cruise, climbout and takeoff, pressure levels were reduced. The main problem was, therefore, to establish pressure correction factors.

Pressure Corrections

Periodically throughout the Phase II Program, test data were obtained at two or more pressure levels, with other operating parameters held constant, to establish pressure correction factors which were assumed to be of the form:

$$K_p = (P_{engine}/P_{test})^n$$

where the pressure exponent (n) is dependent upon the type of emission and operating conditions.

The test data and calculated pressure exponents are presented in Table XXIX. The data have been blocked according to simulated engine condition and fuel staging. Generally, each pair of test points represents a two-to-one variation in combustor inlet pressure. A few of the cases represent a pressure variation of 1.5:1.

Selected values of the exponents, together with statistical analyses of the data, are presented in Table XXX.

The NO_x emissions follow the square root law predicted by simple hot air kinetic calculations quite well for lean, two-stage burning conditions. However, at approach, pilot only conditions, where the primary zone is near or over stoichiometric, a much weaker pressure effect is indicated. Apparently, the prompt NO_x mechanisms, which is virtually independent of pressure, is important under these conditions.

The HC emissions exhibit an inverse linear pressure effect with no strong effect of other operating parameters. Large deviations in the exponent are attributed to the difficulty in accurately sampling low HC concentration levels.

Table XXIX. Effect of Pressure on Emissions, Phase II Full Annular Combustor Tests.

Operating Condition	Conf. No.	Reading Number		Fuel-Air Ratio	Low Pressure Data			Pressure Exponent		
		Low P_1	High P_2		η %	EI_{CO} g/kg	EI_{HC} g/kg	CO (1)	HC (2)	NO_x (3)
Approach, Pilot Only	R1	7	23	0.014	99.3	27.9	0.5	1.26	0.32	0.33
	R3	136	153	0.014	99.6	16.2	0.2	1.18	-0.58	0.30
	D1	37	48	0.014	99.1	35.3	0.4	1.37	-1.00	0.34
	D3	163	168	0.014	98.7	51.5	0.9	0.75	2.20	0.34
		164	167	0.008	99.5	13.6	1.7	1.27	1.30	0.43
	D13	713	705	0.012	99.7	11.8	0.1	1.19	-	0.19
		714	706	0.010	99.9	4.1	0.1	0.84	-	0.09
		715	707	0.008	99.9	2.7	0.1	-	-	0.14
	D14A	783	800	0.012	99.7	12.5	0.4	0.82	0.42	0.27
		784	801	0.010	99.8	6.1	0.2	0.97	0.58	0.16
		785	802	0.008	99.9	3.5	0.3	0.80	0.58	0.03
	D14B	832	822	0.012	99.5	18.3	0.3	0.84	0.78	0.32
		833	823	0.010	99.8	9.2	0.3	0.95	1.26	0.29
		834	821	0.008	99.9	4.7	0.3	0.90	1.00	0.17
		829	822	0.12	99.7	12.9	0.1	0.79	-	0.25
		828	823	0.10	99.8	6.4	0.1	1.02	-	0.26
		826	824	0.008	99.9	3.4	0.1	0.97	-	0.18
Approach, Two-Stage	R1	28	20	0.14	81.9	111.0	155.0	0.10	0.63	0.56
		27	21		88.1	107.0	93.9	0.10	0.44	0.46
	D1	55	46		95.0	76.6	32.6	0.32	0.37	0.33
		53	45		89.7	100.1	79.2	0.30	0.83	0.48
		42	44		92.1	135.6	46.9	0.13	0.46	0.46
		43	47		96.7	83.2	13.5	0.19	0.16	0.37
	D8	533	537		92.3	107.9	52.0	0.24	0.49	0.39
		535	538		91.6	140.8	51.3	0.24	0.74	0.71
	D10	607	595		95.4	65.5	30.5	0.40	0.48	0.42
		608	596		96.3	53.3	24.6	0.53	0.65	0.49
	D11	618	636		99.2	23.5	2.5	0.55	0.47	0.36
		619	637		97.5	47.7	14.2	0.40	0.41	0.44
Climbout, Two-Stage	R3	137	149	0.021	92.2	73.0	60.7	0.15	1.14	0.59
		138	150		96.7	56.4	19.9	0.27	1.37	0.51
		139	151		98.7	33.1	3.7	0.14	1.09	0.42
Takeoff, Two-Stage	R1	14	17	0.023	96.4	53.0	24.0	0.36	1.42	0.57
		12	19		99.6	16.9	0.4	0.30	0.99	0.45
		11	18		98.9	31.7	3.4	0.45	1.15	0.55
	R3	143	146		97.8	43.7	12.1	0.68	1.38	0.34
		144	147		99.1	28.1	2.4	0.91	1.29	0.24
		145	148		99.6	16.0	0.5	0.98	0.18	0.43
	R7	399	401		95.3	60.2	33.3	0.53	0.84	0.66
	D2	99	111		99.6	3.8	3.0	2.01	6.99	0.74
		101	112		99.7	6.1	1.2	1.57	4.50	0.58
		102	113		99.7	8.5	0.9	0.80	3.41	0.55
	D3	174	170		99.8	6.5	0.1	0.89	-	0.51
		175	171		99.8	8.4	0.1	1.12	-	0.53
		176	172		99.7	12.2	0.3	0.78	0	0.48
	D7	446	471		99.9	5.7	0.1	1.07	-	-
		447	473		99.9	4.1	0.1	1.03	-	-
	D10	592	594		99.9	4.9	0	1.09	-	0.58
	D13	750	725		99.9	5.2	0	1.36	-	0.49
		746	725		99.9	2.4	0	1.25	-	0.43
		701	725		100.0	1.4	0	1.18	-	0.29
		747	724		99.9	3.4	0	1.27	-	0.52
		748	723		99.9	4.9	0	1.14	-	0.44
		749	699		99.8	8.2	0	0.96	-	0.35
		711	726	0.020	99.9	5.2	0	0.61	-	0.45
		710	727	0.017	99.7	11.0	0.1	0.55	-	0.49
		709	728	0.014	99.1	34.8	0.8	0.33	0.69	0.58

(1) $\frac{EI_{CO,P2}}{EI_{CO,P1}} = (P_1/P_2)^{n_{CO}}$

(2) $\frac{EI_{HC,P2}}{EI_{HC,P1}} = (P_1/P_2)^{n_{HC}}$

(3) $\frac{EI_{NO_x,P2}}{EI_{NO_x,P1}} = (P_2/P_1)^{n_{NO_x}}$

Table XXX. Summary of Pressure Exponents, Phase II Full Annular Combustor Tests.

Emission	Operating Condition	Pressure Exponent Used, n	Data Statistical Analysis[4] N	$\bar{n}$	σ_n	$\frac{2\sigma_n}{\bar{n}}$
NO_x	Approach					
	Pilot Only	0.2	17[1]	.241	.104	.862
	Two Stage	0.5	12	.456	.102	.450
	Climbout	0.5	3	.507	.085	.336
	Takeoff	0.5	23	.489	.115	.469
HC	All	1.0	38[2]	1.038	1.364	2.628
CO	Pilot Only	$0.6\left(\frac{100}{EI_{CO}}\right)^{0.7} \lesssim 2.0$	4[3]	$0.500\left(\frac{100}{EI_{CO}}\right)^{0.7}$		
	Two Stage	$0.2\left(\frac{100}{EI_{CO}}\right)^{0.7} \lesssim 2.0$	40	$0.191\left(\frac{100}{EI_{CO}}\right)^{0.7}$		

(1) $0.008 \lesssim f \lesssim 0.014$

(2) $EI_{HC,1} \geq 0.2$ g/kg

(3) $f = 0.014$

(4) N = Number of Data Points

$$\bar{n} = \frac{\Sigma n_i}{N} \quad \text{(mean)}$$

$$\sigma_n = \sqrt{\frac{\Sigma n_i^2 - N\bar{n}^2}{N-1}} \quad \text{(standard deviation)}$$

The CO emissions were the most difficult to correlate, and no general explicit relationship with combustor or operating parameters was found. Configuration operating combinations which produced low CO levels at low pressure showed a strong pressure effect. On the other hand, when the configuration/operating combination was such that a high CO level was produced at the low pressure condition, increasing pressure had a weak effect. This characteristic was approximated from early data by the expression:

$$n_{CO} = C \left(\frac{100}{EI_{CO}}\right)^{0.7} \leq 2.0$$

where: $C = 0.2$ for two-stage data

$C = 0.6$ for pilot-stage-only data

Figure 53 presents all of the Phase II Program data and shows that the correlation leaves much to be desired.

Special Configuration D13 Test

At the conclusion of the Double Annular Combustor Configuration D13 evaluations for the Experimental Clean Combustor Program, additional combustor noise tests were conducted under Contract DOT-FA75WA-3688. These evaluations covered a broad range of combustor inlet conditions with a constant fuel-air ratio setting. Exhaust emission data were also obtained (at one rake traverse position). These data allow inlet temperature and pressure, velocity and, to some extent, inlet humidity effects to be assessed. Emission data correlations are shown in Figure 54, 55, and 56. The NO_x emission correlation (Figure 54) is quite good and shows:

1. The linear velocity correction is good over a velocity ratio range of at least 1.5:1.

2. The NASA exponential humidity correction is good over a humidity ratio range of at least 2:1.

3. The exponential temperature correction factor is weaker than has been previously used in the ECCP (195.6 K versus 168.9 K). This new value is, however, in close agreement with some recent GE data.

4. At pressure levels above about four atmospheres, the square root law is good. Apparently below this pressure level, the flame effects upon NO_x formation rates are significant.

The CO emission correlation presented in Figure 55 points out the problem indicated earlier in this appendix. The low inlet temperature data (556 K) show a weak pressure exponent (0.67) while the high temperature data (820 K)

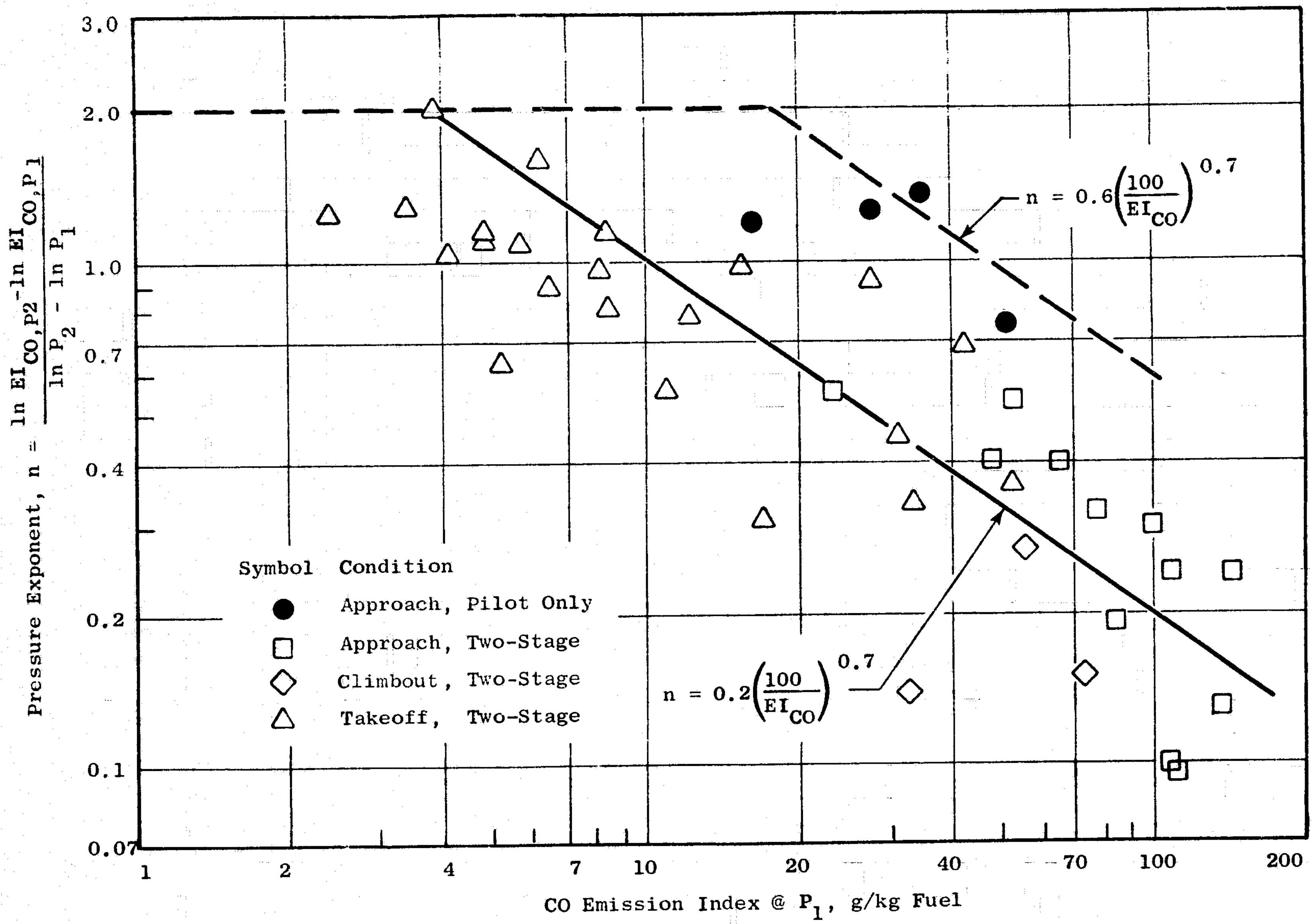

Figure 53. Effect of CO Emission Index on Pressure Exponent, Phase II Program Full Annular Combustor Tests.

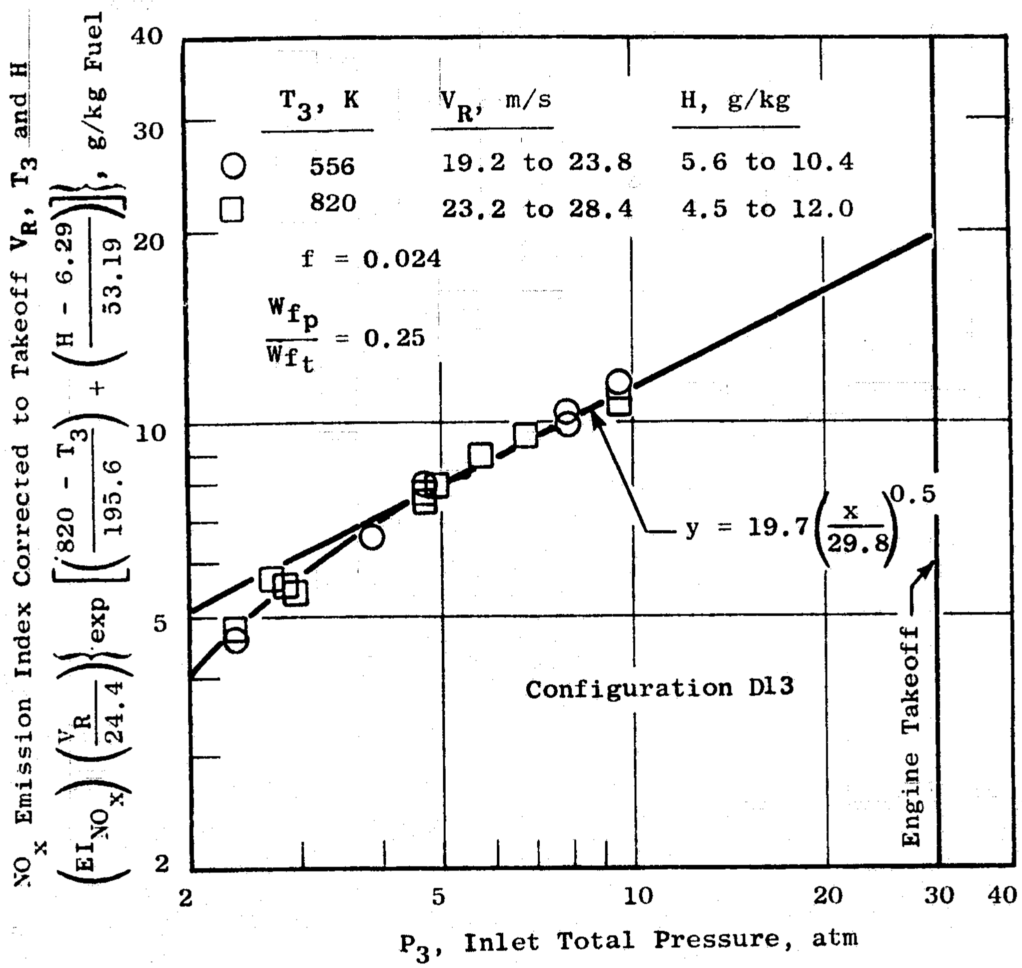

Figure 54. Effect of Pressure on NO_x Emissions, Double Annular Combustor.

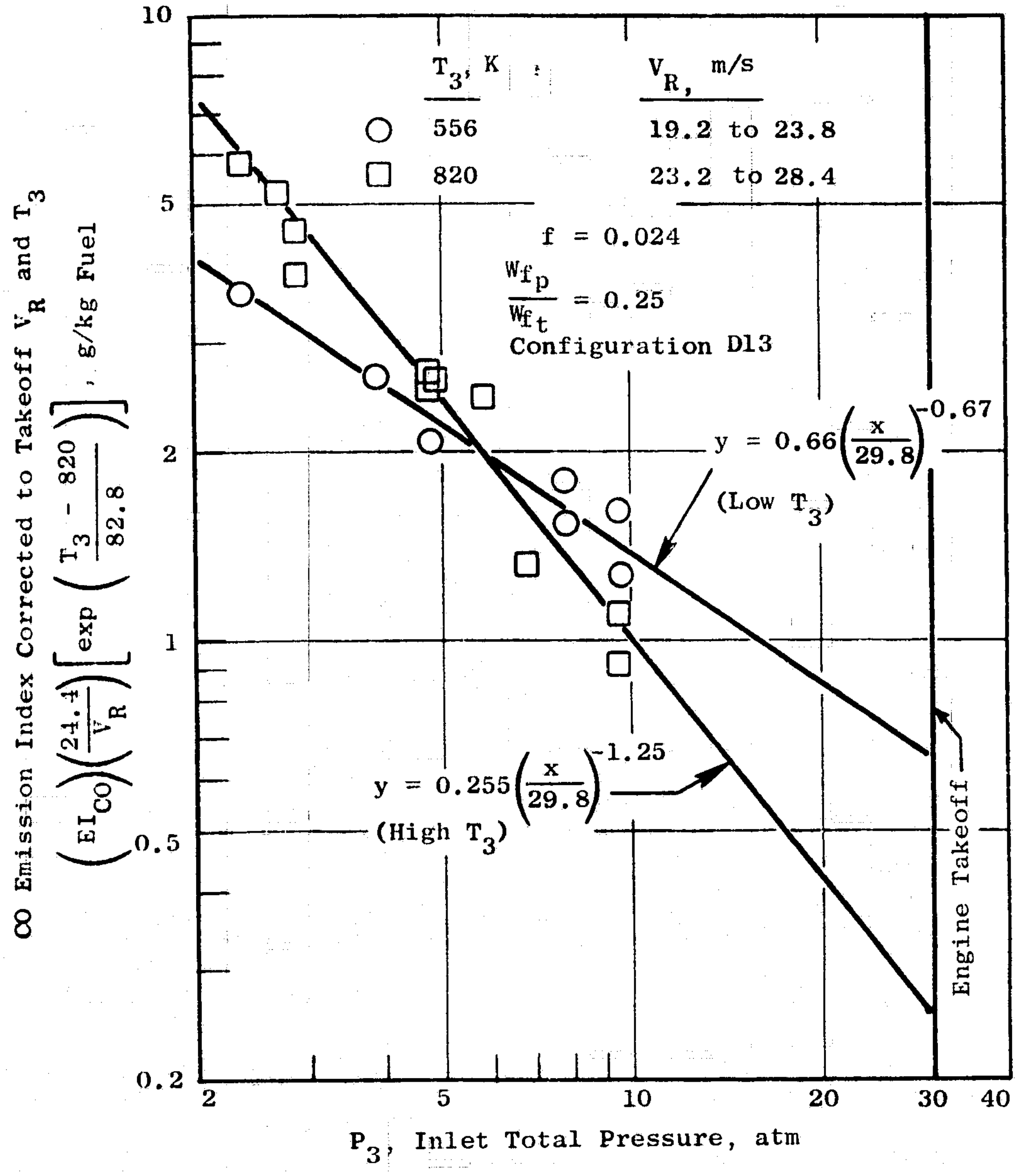

Figure 55. Effect of Pressure on CO Emissions, Double Annular Combustor.

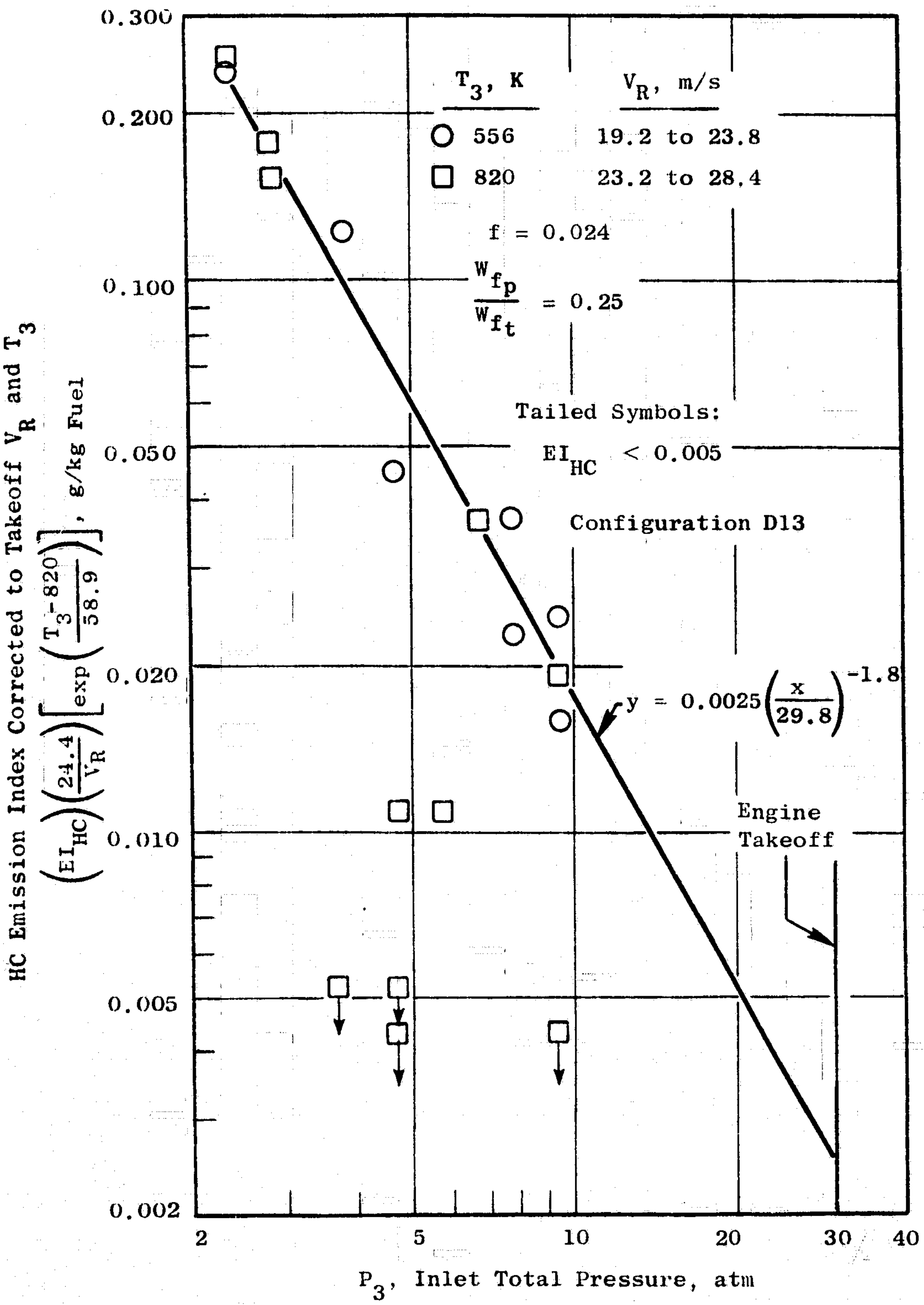

Figure 56. Effect of Pressure on HC Emissions, Double Annular Combustor.

show a much stronger pressure exponent (1.25). Both values are approximately in agreement with the earlier correlation.

The HC emission correction presented in Figure 56 show a strong pressure exponent (1.8) which is within the confidence limits of the earlier data.

APPENDIX B

EPA EMISSION PARAMETER CALCULATION PROCEDURE

This appendix presents calculation procedures which were derived to calculate EPA emission parameters for the Phase II Program test configurations.

The gaseous exhaust emission standards in Reference 2 are expressed in terms of maximum allowable quantity of emission per 1000 pounds-thrust hours, for a prescribed takeoff-landing cycle:

$$EPAP_i = \frac{\sum^{j} \left(\frac{t_j}{60}\right)\left(\frac{W_{f_j}}{1000}\right) EI_{ij}}{\sum^{j} \left(\frac{t_j}{60}\right) \left(\frac{F_{N_j}}{1000}\right)} \tag{1}$$

where

EI = Emission index (lb/1000 lb fuel)
$EPAP$ = Emission parameter (lb/1000 lb thrust-hr)
F_N = Net thrust (lb)
t = Prescribed time (minutes)
W_f = Fuel flow rate (pph)

and the subscripts are:

i = Type of emission (CO, HC, NO_x)
j = Prescribed power level (idle, approach, climbout, and takeoff)

For a particular engine cycle, Equation 1 can be reduced to:

$$EPAP_i = \sum^{j} (C_j) (EI_{ij}) \tag{2}$$

where:

$$C_j = \frac{\left(\frac{t_j}{60}\right) \left(\frac{W_{f_j}}{1000}\right)}{\sum^{j} \left(\frac{t_j}{60}\right) \left(\frac{F_{N_j}}{1000}\right)} \tag{3}$$

The coefficients (C_j) for the CF6-50C engine cycle are derived in Table XXXI, and Equation 2 becomes:

$$EPAP_i = 0.1365\ (EI_{i,\ idle}) + 0.0912\ (EI_{i,\ approach}) + 0.1487\ (EI_{i,\ climb}) + 0.0571\ (EI_{i,\ takeoff}) \tag{4}$$

Alternately, Equation 2 can be expressed as

$$EPAP_i = (EPAP_{i,\ std}) \sum^{j} \frac{EI_{ij}}{\left(\frac{EPAP_{i,std}}{C_j}\right)} \tag{5}$$

where $(EPAP_{i,\ std})$ is the standard for each type of emission. For the CF6-50, Equation 5 becomes:

$$EPAP_{CO} = 4.3 \left[\left(\frac{EI_{CO,\ idle}}{31.49}\right) + \left(\frac{EI_{CO,\ approach}}{47.15}\right) + \left(\frac{EI_{CO,\ climb}}{28.91}\right) + \left(\frac{EI_{CO,\ takeoff}}{75.30}\right)\right] \tag{6a}$$

$$EPAP_{HC} = 0.8 \left[\left(\frac{EI_{HC,\ idle}}{5.859}\right) + \left(\frac{EI_{HC,\ approach}}{8.771}\right) + \left(\frac{EI_{HC,\ climb}}{5.379}\right) + \left(\frac{EI_{HC,\ takeoff}}{14.01}\right)\right] \tag{6b}$$

$$EPAP_{NO_X} = 3.0 \left[\left(\frac{EI_{NO_x,\ idle}}{21.97}\right) + \left(\frac{EI_{NO_x,\ approach}}{32.89}\right) + \left(\frac{EI_{NO_x,\ climb}}{20.17}\right) + \left(\frac{EI_{NO_x,\ takeoff}}{52.53}\right)\right] \tag{6c}$$

Table XXXI. EPAP Coefficients for Phase II Program, CF6-50C Engine.

(Class T_2 Engine)

Power Level	t Minutes	F_N lb_f	W_F[2] pph	$\left(\frac{t}{60}\right)\left(\frac{F_N}{1000}\right)$ Klb_f-hr.	$\left(\frac{t}{60}\right)\left(\frac{W_F}{1000}\right)$ Klb_m- hr.	C lb_m/lb_f-hr.	$\left(\frac{4.3}{C}\right)$	$\left(\frac{0.8}{C}\right)$	$\left(\frac{3.0}{C}\right)$
Idle[1]	26.0	1,692	1,219	0.7331	0.5282	0.1365	31.49	5.859	21.97
Approach	4.0	14,969	5,292	0.9979	0.3528	0.0912	47.15	8.771	32.89
Climb	2.2	42,412	15,692	1.5551	0.5753	0.1487	28.91	5.379	20.17
Takeoff	0.7	49,896	18,938	0.5821	0.2209	0.0571	75.30	14.010	52.53
Σ				3.8682					

$$EPAP_i = \sum^{j} \left[C_j \left(EI_{i_j}\right)\right] = \left(EPAP_{i,\ std}\right) \sum^{j} \left[\frac{EI_{i_j}}{\left(\frac{EPAP_{i,\ std}}{C_j}\right)}\right]$$

$$\left(EPAP_{CO,\ std}\right) = 4.3, \quad \left(EPAP_{HC,\ std}\right) = 0.8, \quad \left(EPAP_{NO_x,\ std}\right) = 3.0\ lb_m/Klb_f\text{-hr.}$$

(1) Assumes no CDP bleed or thrust reverse.

(2) Assumes target levels of combustion efficiency (99.0% at idle, 99.8% elsewhere).

Each term in the summations is the fraction of the total allowable emission produced at that operating mode. Equation 6 was used to calculate the EPAP values of the Phase II Program test configurations which are presented in Chapter III. For the production engine status the same procedure was used except that actual fuel flow rates reflecting actual current engine combustion efficiency levels were used.

Four sample EPAP calculations using this procedure are presented in Table XXXII. The first calculation presents the status of the current production combustor using measured engine data. The next two calculations are for the Double Annular Combustion Configuration D12 rig data corrected to engine pressure levels. The test points for these calculations were selected to illustrate the minimum emission levels obtained without and with fuel staging at approach power level. The final calculation presents one possible combination of emission indices which would meet the standards.

Table XXXII. Sample EPAP Calculations.

- CF6-50C Engine Standard Day Cycle
- Idle Thrust 3.34% of Rated Power
- No Bleed Air Extraction
- NO_x Levels Corrected to Standard Humidity (6.29 g/kg)

a) Current production combustor

Power Level	EI, lb/Klb Fuel CO	HC	NO_x	% $EPAP_{std}$ CO	HC	NO_x
Idle	73.0	30.0	2.5	240.98	532.13	11.83
Approach	4.3	0.01	10.0	9.11	0.11	30.37
Climb	0.3	0.01	29.5	1.04	0.19	146.00
Takeoff	0.2	0.01	35.5	0.26	0.07	67.47
Σ				251.39	532.50	255.67
EPAP, lbm/1000 lb_f thrust-hr.				10.81	4.26	7.67

b) Configuration D12
- Pilot only at approach
- Readings 673,676, 677, and 687 Corrected to engine pressure

Power Level	EI, lb/Klb Fuel CO	HC	NO_x	% $EPAP_{std}$ CO	HC	NO_x
Idle	22.0	2.8	3.1	69.86	47.79	14.11
Approach	3.4	0.1	9.0	7.21	1.14	27.36
Climb	0.8	0.04	14.6	2.77	0.74	72.38
Takeoff	0.1	0.02	19.6	0.13	0.14	37.31
Σ				79.97	49.82	151.17
EPAP, lbm/1000 lb_f thrust-hr.				3.44	0.40	4.54

c) Configuration D12
- Sector staged at approach
- Readings 673,682, 677 and 687 Corrected to engine pressure

Power Level	EI, lb/Klb Fuel CO	HC	NO_x	% $EPAP_{std}$ CO	HC	NO_x
Idle	22.0	2.8	3.1	69.86	47.79	14.11
Approach	10.8	1.4	7.0	22.91	15.96	21.28
Climb	0.8	0.04	14.6	2.77	0.74	72.38
Takeoff	0.1	0.02	19.6	0.13	0.14	37.31
Σ				95.67	64.64	145.09
EPAP, lbm/1000 lb_f thrust-hr.				4.11	0.52	4.35

d) Levels required to meet standards
- (One possible combination)

Power Level	EI, lb/Klb Fuel CO	HC	NO_x	% $EPAP_{std}$ CO	HC	NO_x
Idle	28.3	5.7	3.2	89.87	97.29	14.57
Approach	3.0	0.1	7.0	6.36	1.14	21.28
Climb	1.0	0.04	8.7	3.46	0.74	43.13
Takeoff	0.2	0.02	10.9	0.27	0.14	20.75
Σ				99.96	99.31	99.73
EPAP, lbm/1000 lb_f thrust-hr.				4.30	0.79	2.99

APPENDIX C

FULL ANNULAR RIG TEST DATA

This appendix contains summaries of the operating conditions, combustor performance data and exhaust emission data for each full annular rig test conducted in the Phase II Program. The sequence in which these tests were conducted is presented in Table XXXIII. The detailed summaries (Tables XXXIV through LXVI) are then ordered according to combustor type and configuration number within each combustor type. Descriptions of each of these test configurations and key results are presented in Chapter II and III.

In the data tables, only the measured combustor airflows are shown for the sake of brevity. In conducting the tests, the total airflow and the bleed airflows were actually measured and the combustor airflow was calculated as the difference between these two measured values. Nominally, the combustor airflow was 84 percent of the total inlet airflow.

Within each high pressure performance/exhaust emissions test summary, the data were ordered according to simulated standard day engine operating conditions (idle, approach, cruise when tested, climbout and takeoff). Within each simulated engine operating condition data block, the NO_x and CO emission indices are presented two ways; as actually measured at rig conditions and corrected to true engine operating conditions using the correction procedures described in Chapter II and Appendix A.

Table XXXIII. Full Annular Combustor Test Sequence.

Run (1) Number	Test Date	Configuration Number	Final Reading Number	Noise Measurements	Alternate Fuel Points	Data Table Number
1	10/15/74	R1	28	---	---	LVII
2	10/30	D1	58	---	---	XXXIV
3	11/8	R2	67	---	---	LVIII
4	11/11	R2	88	---	---	LVIII
5	11/16	D2	125	---	---	XXXV
6	1/24/75	R3	141	---	---	LIX
7	1/27	R3	153	---	---	LIX
8	2/5	D3	165	---	---	XXXVI
9	2/6	D3	184	---	---	XXXVI
10	2/10	R4	204	---	---	LX
11	2/28	R5	208	---	---	LXI
12	3/3	R5	225	---	---	LXI
13	3/10	D4	234	---	---	XXXVII
14	2/25	D5	256	---	---	XXXVIII
15	4/7	R6	273	---	---	LXII
16 (2)	4/14	D6	276	---	---	XXXIX, XL
17 (3)	4/15	D6	285	---	---	XLI
18	4/17	D6	298	---	---	XLII
19	4/22	Std	315	---	yes	Ref 9
20	4/23	Std	333	yes	yes	Ref 9
21	4/24	Std	350	---	yes	Ref 9
22 (2)	5/6	R7	363	---	---	LXIII
23 (3)	5/8	R7	374	---	---	LXIV, LXV
24	5/12	R7	416	---	yes	LXVI & Ref 9
25	5/16	D7	457	---	---	XLIII
26	5/19	D7	487	yes	yes	XLIII & Ref 9
27 (4)	6/9	D8	547	---	---	XLIV, XLV
28	6/13	D9	579	---	---	XLVI
29	6/24	D10	608	---	---	XLVII
30	7/8	D11	637	---	---	XLVIII
31	7/14	D12A	657	---	yes	XLIX & Ref 9
32 (3)	7/16	D12A	670	---	---	L, LI
33	8/5	D12B	696	---	---	XLIX
34	8/15	D13	740	yes	yes	LII & Ref 9
35 (5)	8/17	D13	767	yes	---	LII, LIII
36	8/27	D14A	792	---	---	LIV
37	9/2	D14A	807	---	---	LIV
38 (6)	9/3	D14B	820	---	---	LV
39	9/4	D14B	840	---	---	LVI

(1) High pressure emissions/performance test unless noted.
(2) Atmospheric discharge pattern factor test.
(3) Atmospheric discharge sea level ignition/efficiency test.
(4) High pressure emissions/performance & crossfire test.
(5) Noise test conducted under contract DOT-FA75WA-3688.
(6) Sub-atmospheric altitude relight test.

Table XXXIV. Summary of Test Results, Configuration D1.

Reading Number	Point Number	Inlet Total Pressure Atm	Inlet Total Temperature K	Combustor Airflow kg/sec	Total Fuel Flow kg/hr	Inlet Air Humidity g/kg Air	Reference Velocity m/sec	Fuel/Air Ratio g fuel/g air, Metered: Outer Annulus	Metered: Inner Annulus	Metered: Overall	Sample: Overall	Sample Combustion Efficiency %	Emission Indices g/kg Fuel: CO	HC	NO_x	Engine NO_x	Engine CO	SAE Smoke Number	Total Pressure Loss %	Average Exit Temperature K	Profile Factor	Pattern Factor	Notes
29	100	2.99	429	14.3	0	4.9	18.2	0	0	0	--	--	--	--	--	--	--	--	4.31	429	--	--	
33	101	2.92	429	14.1	440	7.4	18.1	0.0087	0	0.0087	0.0108	96.3	57.3	23.7	2.6	2.7	--	--	4.24	760	1.50	2.63	
32	102	2.91	429	13.8	582	7.5	18.0	0.0117	0	0.0117	0.0149	98.0	46.5	9.0	3.4	3.4	--	1	4.18	874	1.54	1.77	
31	103	2.93	428	13.9	694	7.4	18.0	0.0138	0	0.0138	0.0175	98.0	61.6	6.1	3.5	3.5	--	--	4.28	948	1.56	1.17	
30	104	2.93	428	14.0	894	7.0	18.1	0.0178	0	0.0178	0.0248	97.5	83.8	5.6	2.9	2.9	--	--	4.35	1082	1.52	0.90	
34	105	2.93	429	13.1	636	8.7	17.2	0.0135	0	0.0135	0.0175	98.0	56.8	6.9	3.6	3.6	--	--	3.85	938	1.53	1.24	(Sim. 6% Bleed)
35	106	2.94	431	12.2	704	7.2	16.2	0.0160	0	0.0160	0.0208	97.4	78.2	7.3	3.6	3.2	--	--	3.48	1023	1.53	0.97	(Sim. 12% Bleed)
36	601	3.42	451	16.3	673	9.7	19.1	0.0114	0	0.0114	0.0141	98.5	39.1	5.7	3.7	3.4		--	4.62	887	1.56	1.22	
37	201	3.44	620	14.1	698	8.0	22.5	0.0138	0	0.0138	0.0158	99.1	35.3	0.4	7.8	10.6	7.7	1	4.66	1122	1.49	1.11	1, 3
48	211	6.88	631	28.3	1393	8.2	23.0	0.0137	0	0.0137	0.0138	99.6	13.7	0.8	10.3	11.7	4.7	3	4.63	1132	1.54	1.12	3
55	202	3.41	631	13.7	695	6.9	22.6	0.0083	0.0058	0.0141	0.0159	95.0	76.6	32.6	3.9	7.1	56.9	--	4.85	1120	1.24	0.81	2
46	212	6.89	631	27.9	1382	6.0	22.7	0.0080	0.0058	0.0138	0.0155	96.1	61.3	25.2	5.0	6.3	52.8	--	4.65	1118	1.26	0.63	2
56	203	3.40	631	13.7	697	7.2	22.5	0.0063	0.0079	0.0142	0.0164	94.5	81.0	36.0	2.6	4.8	60.8	--	4.82	1121	1.16	0.68	2
57	204	3.42	631	13.9	698	7.8	22.8	0.0043	0.0096	0.0139	0.0161	92.8	96.5	49.8	2.0	3.7	75.0	--	4.86	1105	1.10	0.93	2
58	205	3.35	630	14.0	695	7.6	23.2	0	0.0138	0.0138	0.0156	85.9	78.2	123.1	2.1	4.1	58.1	1	5.46	1064	1.22	1.92	1, 2
53	209	3.38	636	13.8	699	7.6	23.0	0.0082	0.0059	0.0141	0.0152	89.7	100.1	79.2	3.3	6.1	78.1	--	4.74	1099	1.26	0.65	
45	219	6.87	632	27.9	1392	6.0	22.8	0.0081	0.0058	0.0139	0.0151	93.7	81.2	44.0	4.8	6.0	71.8	--	4.73	1109	1.25	0.70	
54	208	3.38	630	13.8	691	7.3	22.8	0.0062	0.0077	0.0139	0.0148	90.7	127.7	63.2	2.2	4.1	103.6	--	4.88	1094	1.14	0.46	
42	207	3.42	635	13.6	709	7.3	22.5	0.0044	0.0101	0.0145	0.0153	92.1	135.6	46.9	2.1	3.7	111.2	--	4.55	1123	1.08	0.28	
44	217	6.83	632	27.4	1394	5.7	22.6	0.0042	0.0099	0.0141	0.0152	93.7	123.5	34.2	2.9	3.6	112.5	--	4.75	1116	1.11	0.33	
43	206	3.40	631	13.7	698	7.3	22.6	0	0.0141	0.0141	0.0156	96.7	83.2	13.5	2.5	4.5	62.8	1	4.90	1132	1.23	0.54	1
47	216	6.89	631	28.3	1402	6.0	23.0	0	0.0138	0.0138	0.0156	97.1	73.0	12.1	3.2	4.1	64.0	--	5.10	1123	1.23	0.56	
38	404	4.83	786	17.2	1300	7.9	25.0	0.0101	0.0108	0.0209	0.0236	99.4	19.4	1.8	10.9	25.5	6.7	--	4.46	1498	1.14	0.30	
39	403	4.76	782	16.8	1295	7.7	24.7	0.0063	0.0151	0.0214	0.0242	99.8	6.2	0.7	6.5	15.5	0.6	--	4.42	1510	1.08	0.21	
40	402	4.76	782	16.8	1308	7.9	24.6	0.0044	0.0172	0.0216	0.0247	99.8	7.3	0.5	6.0	14.4	0.9	1	4.34	1519	1.13	0.35	1
41	401	4.77	782	16.7	1303	7.5	24.5	0.0032	0.0184	0.0216	0.0245	99.7	11.8	0.4	6.1	14.4	2.6	--	4.53	1518	1.16	0.40	
49	504	4.73	820	16.6	1359	7.8	25.6	0.0101	0.0127	0.0228	0.0249	99.8	6.9	0.3	11.2	29.0	0.6	--	4.67	1585	1.10	0.25	
50	503	4.74	820	16.4	1374	7.6	25.4	0.0063	0.0170	0.0233	0.0257	99.9	3.0	0.1	7.2	18.3	0.1	--	4.70	1599	1.09	0.26	
51	502	4.74	820	16.4	1375	7.4	25.3	0.0043	0.0190	0.0233	0.0261	99.9	4.2	0.1	6.4	16.4	0.1	--	4.84	1601	1.15	0.33	
52	501	4.73	820	16.4	1370	7.4	25.4	0.0033	0.0200	0.0233	0.0262	99.8	6.7	0.1	5.9	14.9	0.6	1	4.82	1600	1.17	0.41	1

NOTES:

1. High Density Sampling Mode
2. Alternate Cups Fueled in Inner Annulus
3. Engine NO_x Calculated Using 0.2 Power of P_3

Table XXXV. Summary of Test Results, Configuration D2.

Reading Number	Point Number	Inlet Total Pressure Atm	Inlet Total Temperature K	Combustor Airflow kg/sec	Total Fuel Flow kg/hr	Inlet Air Humidity g/kg Air	Reference Velocity m/sec	Fuel-Air Ratio g fuel / g air — Metered — Outer Annulus	Metered — Inner Annulus	Metered — Over-all	Sample — Over-all	Sample Combustion Efficiency %	Emission Indices g/kg fuel — CO	HC	NO_x	Engine NO_x	Engine CO	SAE Smoke Number	Total Pressure Loss %	Average Exit Temperature K	Profile Factor	Pattern Factor	Notes
90	100	2.98	425	13.8	0	3.0	17.6	0	0	0	--	--	--	--	--	--	--	--	4.23	425	--	--	
91	101	2.93	425	13.8	1043	3.0	17.8	0.0209	0	0.0209	0.0301	97.1	89.1	8.5	2.9	2.8	--	66	4.50	1178	1.58	0.86	
92	102	2.95	431	13.8	891	2.9	17.9	0.0179	0	0.0179	0.0274	97.7	78.1	5.0	3.5	3.1	--	--	4.48	1090	1.52	0.94	
93	103	2.93	431	13.8	693	2.9	18.0	0.0139	0	0.0139	0.0219	98.1	58.2	5.8	4.0	3.6	--	--	4.55	954	1.57	1.15	
94	104	2.94	431	13.7	542	3.1	18.0	0.0110	0	0.0110	0.0166	98.0	44.9	9.8	3.7	3.4	--	1	4.45	850	1.58	1.23	1
95	105	2.93	430	13.8	395	3.0	18.1	0.0079	0	0.0079	0.0114	95.0	76.5	34.5	2.4	2.2	--	--	4.42	729	1.56	1.11	
96	106	2.93	430	13.8	250	2.8	18.0	0.0050	0	0.0050	0.0061	77.3	199.9	180.0	1.3	1.2	--	--	4.44	588	1.50	1.17	
97	201	3.39	636	14.6	690	2.7	24.1	0.0131	0	0.0131	0.0177	99.3	29.1	0.7	9.0	10.8	5.3	0	5.68	1115	1.57	1.42	1,3
115	213	6.80	626	27.9	1385	2.7	22.7	0.0080	0.0058	0.0138	0.0185	96.4	62.8	21.2	7.9	9.7	53.6	--	5.16	1114	1.28	0.72	
114	214	6.77	624	27.5	1392	2.3	22.4	0.0041	0.0100	0.0141	0.0155	95.3	109.2	21.3	3.7	4.6	98.1	--	5.12	1116	1.16	1.36	
116	215	6.79	626	27.8	1394	2.7	22.7	0	0.0140	0.0140	0.0143	97.5	58.7	10.9	4.2	5.1	49.7	1	5.41	1126	--	--	
125	310	4.74	662	19.2	1371	2.7	23.7	0.0198	0	0.0198	0.0337	98.7	53.2	0.3	7.3	7.1	31.9	41	5.34	1354	1.48	0.75	4
124	309	4.73	662	19.1	1423	2.9	23.6	0.0125	0.0082	0.0207	0.0282	98.7	39.7	4.2	9.5	9.3	32.2	--	5.37	1381	1.28	0.59	4
123	308	4.75	663	18.9	1437	2.8	23.3	0.0096	0.0115	0.0211	0.0256	99.1	29.7	2.1	7.4	7.1	23.0	0	5.27	1399	1.14	0.54	4
122	307	4.75	664	19.1	1427	2.9	23.5	0.0063	0.0145	0.0208	0.0233	99.3	26.2	1.3	4.5	4.3	19.8	--	5.60	1391	1.10	0.42	4
121	306	4.73	664	19.1	1427	2.9	23.9	0.0032	0.0175	0.0207	0.0219	98.4	53.0	4.2	3.4	3.2	44.7	--	4.76	1386	1.16	0.59	4
120	324	4.72	730	17.6	1316	3.1	24.1	0.0125	0.0083	0.0208	0.0273	99.2	29.2	1.6	13.2	19.5	19.2	--	5.11	1446	--	--	
119	323	4.73	731	17.7	1312	3.0	24.3	0.0094	0.0112	0.0206	0.0239	99.5	19.1	1.0	10.3	15.2	10.9	0	4.95	1442	--	--	
118	322	4.74	730	17.6	1312	3.1	24.1	0.0064	0.0143	0.0207	0.0235	99.7	10.3	1.0	6.0	8.8	4.3	--	5.22	1446	--	--	
117	321	4.70	733	17.8	1317	3.2	24.5	0.0032	0.0174	0.0206	0.0226	99.2	28.7	1.5	4.6	6.9	18.7	--	5.28	1440	--	--	
107	401	4.72	789	16.8	1307	3.6	25.0	0.0102	0.0114	0.0216	0.0257	99.7	9.9	0.4	15.1	32.5	1.7	--	5.06	1523	1.15	0.37	
108	402	4.73	785	16.7	1307	2.9	24.7	0.0063	0.0154	0.0217	0.0241	99.9	4.9	0.3	7.6	16.3	0.3	--	5.18	1524	1.10	0.37	
109	403	4.78	786	16.9	1310	3.1	24.8	0.0042	0.0173	0.0215	0.0235	99.8	7.6	0.3	6.2	13.3	0.9	0	5.23	1519	1.15	0.66	1
110	404	4.77	785	17.0	1315	3.0	24.9	0.0031	0.0184	0.0215	0.0230	99.6	13.6	0.5	6.3	13.6	3.3	--	5.31	1515	1.14	0.51	
100	501	4.74	822	16.6	1374	2.1	25.6	0.0101	0.0130	0.0231	0.0266	99.7	5.5	1.7	16.3	37.5	0.3	--	5.20	1594	1.12	0.31	
99	502	4.74	821	16.6	1379	1.6	25.6	0.0061	0.0170	0.0231	0.0249	99.6	3.8	3.0	8.2	18.7	0.1	--	5.34	1594	1.10	0.41	
111	522	6.80	822	24.1	1954	2.1	25.9	0.0060	0.0166	0.0226	0.0247	99.9	1.9	0.2	10.5	20.4	0.1	--	5.31	1581	1.10	0.50	
101	503	4.72	822	16.6	1378	2.5	25.6	0.0041	0.0190	0.0231	0.0243	99.7	6.1	1.2	7.4	17.3	0.4	--	5.30	1596	1.14	0.57	
112	523	6.77	823	23.9	1955	2.9	25.8	0.0040	0.0188	0.0228	0.0248	99.9	3.4	0.2	9.1	17.8	0.2	--	5.42	1588	1.14	0.39	
102	504	4.72	822	16.5	1380	2.9	25.6	0.0031	0.0202	0.0233	0.0254	99.7	8.5	0.9	7.8	18.1	1.0	1	5.34	1601	1.15	0.54	1
113	524	6.80	825	23.6	1955	2.8	25.6	0.0031	0.0198	0.0229	0.0241	99.8	6.3	0.3	9.6	18.4	0.8	1	5.34	1593	1.17	0.45	
103	505	4.71	822	16.5	1376	2.4	25.6	0	0.0232	0.0232	0.0244	99.8	7.8	0.5	9.7	22.5	0.8	--	5.42	1599	1.17	0.50	
104	506	4.74	822	16.4	1130	2.4	25.4	0	0.0192	0.0192	0.0205	99.8	7.2	0.6	8.4	19.2	0.7	--	5.11	1474	1.18	0.61	
105	507	4.74	823	16.3	889	2.4	25.3	0	0.0152	0.0152	0.0175	99.8	8.5	0.5	7.9	17.9	1.0	--	5.00	1350	--	--	2
106	508	4.74	823	16.3	647	2.7	25.4	0	0.0110	0.0110	0.0114	99.0	33.9	1.6	7.8	17.8	14.8	--	4.86	1210	1.22	0.64	

Notes:

1. High Density Sampling Mode
2. Single Position Sampling Mode
3. Engine NO_x Calculated Using 0.2 Power of P_3
4. Cruise Condition-Mach No. = 0.85, Altitude = 12.8 km

Table XXXVI. Summary of Test Results, Configuration D3.

Reading Number	Point Number	Inlet Total Pressure Atm	Inlet Total Temperature K	Combustor Airflow kg/sec	Total Fuel Flow kg/hr	Inlet Air Humidity g/kg Air	Reference Velocity m/sec	Fuel-Air Ratio g fuel/ g air, Metered: Outer Annulus	Metered: Inner Annulus	Metered: Over-All	Sample: Over-All	Sample Combustion Efficiency %	Emission Indices g/kg fuel: CO	HC	NO_x	Eng NO_x	Eng CO	SAE Smoke Number	Total Pressure Loss %	Average Exit Temperature K	Profile Factor	Pattern Factor	Notes
155	100	2.91	426	13.8	0	--	18.1	0	0	0	0	--	--	--	--	--	--	--	3.71	431	--	--	
156	101	2.96	429	14.1	531	2.0	18.2	0.0105	0	0.0105	0.0133	94.7	67.0	37.6	3.3	3.0	--	2	3.98	817	1.56	1.55	
157	101	2.93	428	13.8	531	2.0	18.0	0.0106	0	0.0106	0.0137	94.7	68.2	36.9	3.3	3.0	--	--	3.86	821	--	--	1
158	102	2.94	428	14.0	386	2.2	18.2	0.0076	0	0.0076	0.0095	91.8	77.4	63.7	2.9	2.7	--	--	3.90	708	1.55	1.78	
159	103	2.91	428	13.1	616	4.3	17.4	0.0130	0	0.0130	0.0163	94.4	80.5	37.6	3.3	3.1	--	--	3.58	903	1.52	1.29	6% Bld.
160	104	2.87	429	12.3	678	3.4	16.6	0.0153	0	0.0153	0.0190	94.1	90.8	37.6	3.1	2.9	--	--	3.27	980	1.51	1.10	12% Bld.
161	105	3.56	458	16.9	623	3.0	19.3	0.0102	0	0.0102	0.0123	96.9	50.8	19.5	4.2	4.1	--	--	4.11	843	1.52	1.51	4.8% F_N
162	106	4.50	490	21.1	767	4.5	20.2	0.0101	0	0.0101	0.0127	98.6	33.2	6.6	5.0	5.5	--	1	4.37	875	1.52	1.43	7.0% F_N
165	200	3.10	636	14.2	0	--	25.1	0	0	0	0	--	--	--	--	--	--	--	5.47	631	--	--	
166	210	6.76	629	27.7	0	--	22.9	0	0	0	0	--	--	--	--	--	--	--	4.21	629	--	--	
163	202	3.43	629	13.9	694	5.0	22.7	0.0139	0	0.0139	0.0162	98.7	51.5	0.9	6.9	8.5	16.2	2	4.31	1131	1.52	1.36	2, 3
168	212	6.79	628	27.5	1398	3.1	22.6	0.0141	0	0.0141	0.0181	99.3	30.8	0.2	9.0	9.3	14.9	16	4.33	1141	1.53	1.33	3
164	203	3.42	632	14.0	397	4.6	23.0	0.0079	0	0.0079	0.0095	99.5	13.6	1.7	8.7	10.0	1.2	--	4.25	936	1.50	1.74	3
167	213	6.78	627	27.5	793	3.0	22.7	0.0080	0	0.0080	0.0100	99.8	5.7	0.7	11.7	12.4	1.9	--	4.21	926	1.53	1.51	3
169	214	6.78	628	27.5	499	2.5	22.6	0.0050	0	0.0050	0.0057	99.2	22.8	2.8	8.5	8.7	16.8	--	4.21	821	1.53	1.59	3
181	401	4.74	786	17.0	1289	2.7	25.1	0.0098	0.0112	0.0210	0.0242	99.4	22.2	0.8	13.6	29.3	8.4	--	4.39	1500	1.24	0.64	
182	402	4.75	786	17.0	1313	3.4	25.2	0.0061	0.0154	0.0215	0.0242	99.8	9.3	0.2	9.7	21.1	1.6	--	4.34	1516	1.14	0.38	
183	403	4.73	787	17.0	1313	3.3	25.2	0.0040	0.0174	0.0214	0.0244	99.7	11.7	0.2	8.2	17.9	2.5	0	4.30	1515	1.18	0.45	2
184	404	4.74	788	17.2	1307	3.5	25.5	0.0029	0.0182	0.0211	0.0245	99.5	17.2	0.6	8.0	17.7	5.4	--	4.54	1505	1.18	0.47	
173	501	4.76	820	19.3	1373	2.3	25.3	0.0102	0.0132	0.0234	0.0263	99.7	11.1	0.2	15.7	35.9	2.2	--	4.29	1602	1.20	0.54	
174	502	4.72	821	19.3	1363	3.0	25.5	0.0060	0.0171	0.0231	0.0258	99.8	6.5	0.1	11.1	25.9	0.6	--	4.39	1595	1.14	0.34	
170	512	6.80	821	23.2	1964	2.1	25.2	0.0060	0.0175	0.0235	0.0264	99.9	4.7	0.4	13.7	26.0	0.5	--	4.38	1608	1.13	0.37	
175	503	4.73	820	16.4	1378	1.9	25.2	0.0041	0.0193	0.0234	0.0258	99.8	8.4	0.1	10.3	23.8	1.0	--	4.31	1603	1.16	0.38	
171	513	6.80	820	23.0	1965	2.6	25.0	0.0042	0.0195	0.0237	0.0265	99.9	5.6	0.2	12.6	24.1	0.7	--	4.18	1613	1.15	0.42	
176	504	4.73	820	16.5	1377	2.2	25.5	0.0030	0.0203	0.0233	0.0260	99.7	12.2	0.3	10.4	24.0	2.5	0	4.33	1598	1.17	0.49	2
172	514	6.80	820	23.5	1966	2.4	25.4	0.0031	0.0202	0.0233	0.0257	99.8	9.2	0.3	12.3	23.8	2.0	1	4.24	1599	1.18	0.46	
177	505	4.72	820	16.3	1373	3.2	25.3	0	0.0234	0.0234	0.0255	99.6	15.9	0.4	12.0	28.0	4.2	--	4.37	1603	1.20	0.52	
178	506	4.74	821	16.3	1127	3.2	25.3	0	0.0192	0.0192	0.0208	99.6	14.3	0.5	10.3	24.0	3.4	--	4.30	1476	1.21	0.54	
179	507	4.76	821	16.3	880	2.7	25.2	0	0.0150	0.0150	0.0160	99.4	20.1	0.9	9.1	20.9	6.5	--	4.26	1341	1.24	0.61	
180	508	4.74	822	16.5	645	3.2	25.5	0	0.0109	0.0109	0.0117	98.6	49.4	3.0	8.0	18.7	27.0	--	4.25	1204	1.23	0.59	

Notes:

1. Radial Immersion Sampling Mode
2. High Density Sampling Mode
3. Engine NO_x Calculated Using 0.2 Power of F_3

Table XXXVII. Summary of Test Results, Configuration D4.

Reading Number	Point Number	Inlet Total Pressure Atm	Inlet Total Temperature K	Combustor Airflow kg/sec	Total Fuel Flow kg/hr	Inlet Air Humidity g/kg Air	Reference Velocity m/sec	Fuel-Air Ratio g fuel/g air: Metered Outer Annulus	Metered Inner Annulus	Metered Over-All	Sample Over-All	Sample Combustion Efficiency %	Emission Indices g/kg fuel: CO	HC	NO_x	Engine NO_x	Engine CO	SAE Smoke Number	Total Pressure Loss %	Average Exit Temperature K	Profile Factor	Pattern Factor	Notes
227	100	2.89	429	13.9	0	---	18.3	0	0	0	---	---	---	---	---	---	---	---	4.11	429	---	---	
229	105	2.90	434	13.9	777	3.1	18.4	0.0155	0	0.0155	0.0178	97.7	85.0	3.3	3.2	3.0	---	---	4.30	1010	1.39	1.07	
228	101	2.91	434	13.8	694	3.1	18.3	0.0139	0	0.0139	0.0157	98.1	63.0	3.9	3.6	3.3	---	---	4.27	958	1.38	1.15	
230	102	2.91	434	13.9	548	3.1	18.3	0.0110	0	0.0110	0.0121	98.5	39.1	6.2	4.3	3.9	---	---	4.19	856	1.31	1.02	
231	102	2.91	434	13.8	547	3.1	18.2	0.0110	0	0.0110	0.0103	98.3	41.0	7.8	4.5	4.1	---	---	4.17	855	---	---	1
232	103	2.90	432	13.8	396	3.1	18.3	0.0080	0	0.0080	0.0081	95.4	58.5	32.4	2.9	2.7	---	---	4.16	733	1.31	1.30	2, 3
233	104	2.89	426	14.0	299	2.3	18.3	0.0059	0	0.0059	0.0054	74.4	145.4	221.7	0.9	0.9	---	---	4.09	604	1.32	1.89	2
234	200	3.16	629	14.2	0	---	24.6	0	0	0	---	---	---	---	---	---	---	---	5.19	629	---	---	

Notes:
1. Radial Immersion Sampling Mode
2. Data Taken after Fuel Nozzle Developed Leak
3. High Density Sampling Mode

Table XXXVIII. Summary of Test Results, Configuration D5.

Reading Number	Point Number	Inlet Total Pressure Atm	Inlet Total Temperature K	Combustor Airflow kg/sec	Total Fuel Flow kg/hr	Inlet Air Humidity g/kg Air	Reference Velocity m/sec	Fuel-Air Ratio g fuel/g air: Metered Outer Annulus	Metered Inner Annulus	Metered Overall	Sample Overall	Sample Combustion Efficiency %	Emission Indices g/kg fuel: CO	HC	NO_x	Engine NO_x	Engine CO	SAE Smoke Number	Total Pressure Loss %	Average Exit Temperature K	Profile Factor	Pattern Factor	Notes
235	100	2.94	428	16.0	0	---	18.6	0	0	0	---	---	---	---	---	---	---	---	5.48	428	---	---	
236	100	2.90	431	13.7	0	---	18.2	0	0	0	---	---	---	---	---	---	---	---	4.10	431	---	---	
237	101	2.91	430	13.9	699	2.8	18.2	0.0140	0	0.0140	0.0197	98.1	76.4	1.0	3.4	3.2	---	---	4.38	956	1.42	1.28	
238	102	2.91	430	13.8	536	2.8	18.1	0.0108	0	0.0108	0.0128	98.9	38.0	2.[illegible]	4.0	3.7	---	---	4.45	847	1.31	1.16	1
239	102	2.92	431	13.7	538	2.7	18.0	0.0109	0	0.0109	0.0124	98.9	38.4	2.5	4.0	3.6	---	---	4.42	852	1.27	0.87	2
240	103	2.92	431	13.8	444	2.7	18.1	0.0089	0	0.0089	0.0099	99.3	20.1	2.2	4.2	3.8	---	---	4.60	781	1.26	0.92	
242	103	2.91	431	13.7	440	2.7	18.2	0.0089	0	0.0089	0.0101	99.3	19.8	2.2	4.2	3.8	---	---	4.73	779	1.26	0.93	
241	104	2.91	431	13.7	362	2.7	18.1	0.0073	0	0.0073	0.0078	98.9	23.0	5.5	3.3	3.0	---	---	4.63	719	1.24	0.92	
243	201	3.40	632	13.7	691	2.6	22.6	0.0140	0	0.0140	0.0172	98.9	45.6	0.1	6.7	7.7	13.1	---	4.67	1139	1.37	1.34	1, 3
244	202	3.40	632	13.7	536	2.5	22.9	0.0108	0	0.0108	0.0138	99.5	20.9	0.1	8.9	10.3	2.4	---	4.90	1034	1.37	1.60	3
245	203	3.40	629	13.7	391	2.5	22.6	0.0079	0	0.0079	0.0095	99.9	5.4	0.1	9.8	11.4	0.5	---	4.11	928	1.31	1.78	3
246	204	3.41	629	13.8	242	2.5	22.6	0.0049	0	0.0049	0.0056	99.3	21.4	1.8	5.0	5.8	2.6	---	4.79	816	1.29	1.62	3
254	401	4.79	785	17.1	1313	2.6	25.1	0.0103	0.0110	0.0213	0.0244	99.4	22.1	0.5	12.9	27.7	8.0	---	4.91	1508	1.21	0.47	
253	402	4.78	783	17.2	1290	2.0	25.1	0.0060	0.0148	0.0208	0.0237	99.8	9.4	0	7.8	16.9	1.5	---	4.97	1494	1.14	0.31	
252	403	4.84	783	17.1	1298	2.0	24.7	0.0041	0.0170	0.0211	0.0238	99.8	8.6	0	7.2	15.1	1.2	---	4.82	1505	1.13	0.38	1
256	522	8.54	821	29.5	2453	2.6	25.4	0.0064	0.0167	0.0231	0.0262	99.9	2.2	0.1	13.1	22.6	0.2	---	4.78	1596	1.13	0.36	
255	523	8.53	821	29.5	2454	2.6	25.4	0.0054	0.0177	0.0231	0.0261	100.0	2.0	0.1	12.5	21.6	0.2	---	4.85	1598	1.14	0.34	

Notes:

1. High Density Sampling Mode
2. Radial Immersion Sampling Mode
3. Engine NO_x Calculated Using 0.2 Power of P_3

Table XXXIX. Pattern and Profile Factors for Atmospheric Pressure Combustor Test, Configuration D6.

Point Number	Inlet Total Pressure atm	Inlet Total Temperature K	Combustor Airflow kg/s	Fuel-Air Ratio g Fuel/g Air			Pattern Factor	Profile Factor
				Pilot	Main	Total		
20	1.05	626	4.01	.0145	0	.0145	1.01	1.16

Table XL. Summary of Sea Level Ignition Test Results, Configuration D6.

Point Number	Inlet Total Pressure atm	Inlet Total Temperature K	Combustor Airflow kg/s	Type Ignitor	Required Fuel Flows (kg/hr)				
					Lightoff	50% Propagation	100% Propagation	50% Cups Out	Lean Blowout
50	-	287	2.72	spark	337	364	377	-	-
60	1.01	284	3.58	torch	401	409	417	375	303
					379	-	433	380	262
					418	418	432	382	305
80	1.02	282	4.51	spark	428	429	429	356	202
					428	435	439	364	207
					423	440	440	360	205
70	1.03	283	5.47	spark	418	432	447	353	210
					428	457	460	304	183
					428	449	459	291	181
70	1.03	284	5.53	torch	399	416	482	-	-

Notes:

a. JP-5 at 285 K

b. Barometric pressure = .987 atmospheres

Table XLI. Summary of Sea Level Efficiency Test Results, Configuration D6.

Point Number	Inlet Total Pressure atm	Inlet Total Temperature K	Combustor Airflow kg/s	Metered Fuel-Air Ratio g Fuel/g Air	Measured Temperature Rise K	Combustor Efficiency %
83	1.03	284	4.52	.0278	565	54.4
72	1.04	284	5.42	.0210	364	44.5
73	1.04	284	5.46	.0230	485	54.7
73	1.04	285	5.52	.0243	546	58.9

Notes:

a. JP-5 at 285 K

b. Barometric pressure = .987 atmospheres

Table XLII. Summary of Test Results, Configuration D6.

Reading Number	Point Number	Inlet Total Pressure Atm	Inlet Total Temperature K	Combustor Airflow kg/sec	Total Fuel Flow kg/hr	Inlet Air Humidity g/kg Air	Reference Velocity m/sec	Fuel-Air Ratio g fuel/ g Air, Metered, Outer Annulus	Metered, Inner Annulus	Metered, Over-All	Sample, Over-All	Sample Combustion Efficiency %	Emission Indicies g/kg fuel, CO	HC	NO_x	Eng NO_x	Eng CO	SAE Smoke Number	Total Pressure Loss %	Average Exit Temperature K	Profile Factor	Pattern Factor	Notes
286	100	2.93	431	13.7	0	5.1	18.0	0	0	0	0	--	--	--	--	--	--	--	4.36	431	--	--	
287	101	2.94	430	13.9	691	5.1	18.0	0.0138	0	0.0138	0.0167	98.5	54.0	2.2	3.5	3.4	--	--	4.55	951	1.21	0.99	
288	102	2.94	430	13.6	539	5.6	17.9	0.0110	0	0.0110	0.0125	99.2	24.7	2.1	3.9	3.8	--	1	4.39	857	1.14	0.95	1
289	102	2.95	432	13.7	537	5.0	17.9	0.0109	0	0.0109	0.0122	99.1	27.0	2.3	4.0	3.8	--	--	4.43	853	1.12	0.98	2
290	103	2.94	429	13.8	444	5.4	18.0	0.0089	0	0.0089	0.0097	99.3	18.5	2.4	3.7	3.6	--	--	4.48	779	1.10	0.88	
291	104	2.93	429	13.7	346	4.7	17.9	0.0070	0	0.0070	0.0084	97.5	43.7	15.3	2.1	2.0	--	--	4.43	701	1.12	1.46	
292	201	3.40	628	13.4	697	4.0	22.1	0.0144	0	0.0144	0.0180	99.2	32.1	0.1	8.1	9.6	6.4	1	4.60	1152	1.09	1.16	1 2, 3
293	202	3.41	629	13.6	549	4.1	22.3	0.0113	0	0.0113	0.0135	99.7	11.4	0.1	8.8	10.4	1.0	--	4.71	1046	1.09	1.13	3
294	203	3.42	631	13.7	400	4.4	22.5	0.0081	0	0.0081	0.0095	99.9	3.0	0.1	7.2	8.6	0.3	1	4.77	938	1.14	1.30	3

Notes:
1. High Density Sampling Mode
2. Radial Immersion Sampling Mode
3. Engine NO_x Calculated Using 0.2 Power of P_3

Table XLIII. Summary of Test Results, Configuration D7.

Reading Number	Point Number	Inlet Total Pressure Atm	Inlet Total Temperature K	Combustor Airflow kg/sec	Total Fuel Flow kg/hr	Inlet Air Humidity g/kg Air	Reference Velocity m/sec	Fuel-Air Ratio g Fuel/g Air: Metered			Fuel-Air Ratio: Sample Overall	Sample Combustion Efficiency %	Emission Indices g/kg Fuel					SAE Smoke Number	Total Pressure Loss, %	Average Exit Temperature K	Profile Factor	Pattern Factor	Notes
								Outer Annulus	Inner Annulus	Overall			CO	HC	NO_x (1)	Engine NO_x (1)	Engine CO						
417	100	2.92	424	14.1	0	---	18.1	0	0	0	---	---	---	---	---	---	---	---	4.56	424	---	---	
458	100	2.92	430	13.7	0	---	18.0	0	0	0	---	---	---	---	---	---	---	---	4.48	430	---	---	
450	101	2.90	433	13.6	697	10.4	18.1	.0142	0	.0142	.0207	99.0	39.9	1.1	---	---	---	0.8	4.69	971	1.31	1.07	
451	102	2.90	433	13.8	582	7.2	18.2	.0117	0	.0117	.0159	99.4	20.7	1.3	---	---	---	0.7	5.04	885	1.29	1.00	
474	102	2.93	429	13.7	576	6.0	17.9	.0117	0	.0117	.0153	99.3	24.9	1.3	---	---	---	0.8	4.55	878	1.25	1.01	
487	102	2.95	426	13.8	577	7.3	17.9	.0116	0	.0116	.0167	99.6	16.7	0.6	---	---	---	---	4.78	875	1.28	1.14	
452	103	2.91	433	13.8	499	6.5	18.2	.0100	0	.0100	.0127	99.4	18.6	1.9	---	---	---	0.6	4.84	824	1.26	0.87	
453	104	2.91	433	13.8	394	6.5	18.3	.0079	0	.0079	.0092	98.5	33.3	7.0	---	---	---	0.6	4.88	742	1.23	0.90	
437	105	3.33	432	13.0	1681	6.2	15.6	.0110	.0248	.0358	.0383	97.6	61.8	9.6	---	---	---	---	4.18	1633	---	---	
440	201	3.40	626	13.9	700	6.3	22.7	.0140	0	.0140	.0176	99.4	25.9	0.4	---	---	3.8	0.6	5.14	1135	1.28	1.07	2,3
439	202	3.40	625	13.9	582	6.3	22.8	.0116	0	.0116	.0148	99.7	12.6	0.4	---	---	1.1	---	5.20	1056	1.28	1.03	3
438	203	3.44	625	14.0	398	7.1	22.6	.0079	0	.0079	.0094	99.8	3.6	0.9	---	---	0.3	---	5.05	925	1.27	1.03	3
441	204	3.43	625	13.8	1317	6.0	22.4	.0142	.0124	.0266	.0312	98.1	45.2	5.0	---	---	28.8	---	5.43	1529	1.21	0.55	
443	205	3.44	625	13.8	1003	6.0	22.3	.0082	.0120	.0202	.0235	97.7	56.9	10.2	---	---	38.8	---	5.30	1327	1.14	0.33	
444	401	4.77	776	17.0	1312	6.4	24.8	.0040	.0175	.0215	.0246	99.7	10.5	0.2	---	---	1.9	0.4	5.17	1509	1.10	0.56	2
445	402	4.76	781	16.9	1312	6.1	21.9	.0062	.0153	.0215	.0244	99.8	8.8	0.3	---	---	1.3	---	5.04	1515	1.10	0.38	
449	403	4.76	785	16.5	1308	6.1	24.4	.0058	.0162	.0220	.0248	99.8	6.9	0.2	---	---	0.8	0.7	4.80	1534	1.12	0.41	
454	511	9.50	822	32.7	2733	5.1	25.3	.0059	.0173	.0232	.0267	100.0	1.8	0.1	---	---	0.2	1.7	4.92	1601	1.12	0.51	2
455	512	9.51	818	32.5	2366	5.2	25.3	.0062	.0138	.0200	.0231	99.9	1.8	0.1	---	---	0.6	1.7	4.79	1499	1.12	0.35	
456	513	9.52	817	32.6	2013	5.3	25.1	.0062	.0110	.0172	.0197	99.6	14.8	0.3	---	---	6.0	1.3	4.76	1408	1.11	0.28	
457	514	9.49	821	32.9	1648	5.2	25.1	.0061	.0078	.0139	.0165	99.1	33.3	1.4	---	---	19.9	1.5	4.71	1305	1.14	0.36	
446	505	4.77	820	16.6	1371	6.3	25.5	.0040	.0190	.0230	.0253	99.9	5.7	0.1	---	---	0.4	0.5	5.18	1587	1.11	0.46	2
471	515	9.57	820	33.1	2751	5.9	25.4	.0041	.0190	.0231	.0257	99.9	2.7	0	---	---	0.3	0.5	5.05	1595	1.12	0.49	
447	506	4.77	819	16.6	1373	6.1	25.6	.0062	.0169	.0231	.0257	99.9	4.1	0.1	---	---	0.1	0.8	5.04	1589	1.11	0.45	
473	516	9.57	819	33.2	2727	5.9	25.6	.0061	.0167	.0228	.0253	100.0	2.0	0	---	---	0.2	1.1	4.92	1585	1.13	0.38	
448	507	4.78	820	16.4	1376	6.0	25.2	.0104	.0129	.0233	.0270	99.8	7.3	0.1	---	---	0.8	---	4.88	1600	1.15	0.46	
472	518	9.57	820	33.1	2715	5.9	25.4	.0081	.0149	.0230	.0261	100.0	2.2	0	---	---	0.2	0.9	4.96	1591	1.12	0.31	

NOTES:

1. NO_x Data Suspect (Low)
2. High Density Sampling Mode
3. Engine NO_x Calculated Using 0.2 Power of P_3

Table XLIV. Summary of Test Results, Configuration D8.

Reading Number	Point Number	Inlet Total Pressure Atm	Inlet Total Temperature K	Combustor Airflow kg/sec	Total Fuel Flow kg/hr	Inlet Air Humidity g/kg Air	Reference Velocity m/sec	Fuel-Air Ratio g fuel / g air, Metered: Outer Annulus	Metered: Inner Annulus	Metered: Over-All	Sample Over-All	Sample Combustion Efficiency %	Emission Indices g/kg fuel: CO	HC	NO_x	Engine NO_x	Engine CO	SAE Smoke Number	Total Pressure Loss %	Average Exit Temperature K	Profile Factor	Pattern Factor	Notes
488	100	3.01	429	13.8	0	4.3	17.6	0	0	0	-	-	-	-	-	-	-	-	4.51	429	-	-	
489	101	2.93	431	13.8	694	10.0	18.1	.0140	0	.0140	.0178	99.0	36.9	1.3	2.9	3.0	-	-	4.94	961	1.36	1.04	
490	102	2.94	428	13.9	579	5.4	18.0	.0116	0	.0116	.0137	99.2	24.3	1.9	3.2	3.1	-	1	4.78	897	1.38	1.05	1
491	103	2.94	431	13.8	445	5.7	18.0	.0090	0	.0090	.0106	99.2	18.5	3.3	2.9	2.8	-	-	4.87	782	1.28	0.77	
492	104	2.94	430	13.9	344	5.7	18.0	.0069	0	.0069	.0080	95.3	65.0	31.6	1.8	1.8	-	-	4.71	693	1.46	1.75	
536	201	3.39	628	14.1	694	7.6	23.1	.0137	0	.0137	.0148	99.5	21.2	0.5	6.4	8.4	2.5	2	5.39	1128	1.35	1.07	1, 2
533	202	3.41	628	14.0	704	7.4	22.9	.0070	.0069	.0139	.0151	92.3	107.9	52.0	3.5	6.6	85.4	-	5.55	1100	1.27	0.62	
534	203	3.40	626	14.0	700	7.2	22.9	.0056	.0083	.0139	.0149	92.1	123.0	50.1	2.8	5.3	99.3	2	5.67	1098	1.19	0.43	
535	204	3.39	628	14.0	688	7.1	23.0	.0044	.0093	.0137	.0146	91.6	140.8	51.3	2.2	4.2	115.8	-	5.80	1088	1.13	0.40	
537	212	6.80	630	27.7	1391	6.0	22.9	.0071	.0069	.0140	.0153	94.2	91.7	37.0	4.8	6.1	81.7	-	5.32	1113	1.25	0.52	
538	213	6.80	631	27.6	1387	5.4	22.8	.0046	.0094	.0140	.0150	94.2	119.3	30.6	3.8	4.8	108.4	2	5.34	1113	1.12	0.36	
539	214	6.81	627	27.6	1388	5.7	22.6	.0092	.0048	.0140	.0155	94.6	69.9	37.6	5.6	7.2	60.8	-	5.23	1112	1.39	0.90	
542	401	4.76	781	17.1	1310	4.7	25.0	.0042	.0171	.0213	.0234	99.9	4.8	0.1	6.6	15.3	0.3	-	5.31	1509	1.08	0.34	
541	402	4.76	783	17.0	1297	5.3	25.0	.0062	.0150	.0212	.0233	99.9	4.4	0.1	7.7	17.7	0.2	3	5.27	1508	1.07	0.29	1
540	403	4.76	778	17.0	1301	7.6	24.8	.0081	.0132	.0213	.0229	99.8	7.0	0.3	8.3	20.4	0.8	-	5.20	1506	1.12	0.34	
543	404	4.76	781	17.0	1309	4.7	25.0	.0033	.0181	.0214	.0235	99.8	6.9	0.1	6.5	14.8	0.8	-	5.33	1511	1.08	0.33	
546	501	4.76	820	16.5	1373	4.6	25.4	.0042	.0189	.0231	.0246	99.9	2.8	0	8.1	19.6	0.1	-	5.28	1594	1.08	0.31	
547	502	4.76	819	16.5	1366	4.5	25.4	.0062	.0169	.0231	.0246	99.9	2.3	0.1	9.0	21.8	0.1	1	5.20	1594	1.08	0.27	1
544	503	4.75	812	16.5	1369	4.4	25.2	.0082	.0149	.0231	.0247	99.9	2.4	0.1	9.9	24.9	0.1	-	5.12	1589	1.10	0.30	
545	504	4.76	815	16.5	1371	4.5	25.3	.0031	.0200	.0231	.0252	99.9	4.6	0.1	8.0	19.7	0.2	-	5.28	1591	1.08	0.35	

Notes:

1. High Density Sampling Mode
2. Engine NO_x Calculated Using 0.2 Power of P_3

Table XLV. Summary of Cross-fire Test Results, Configuration D8.

Reading Number	Point Number	Inlet Total Pressure Atm	Inlet Total Temperature K	Combustor Airflow kg/sec	Total Fuel Flow kg/hr	Inlet Air Humidity g/kg Air	Reference Velocity m/sec	Fuel-Air Ratio g fuel/g air: Metered Outer Annulus	Metered Inner Annulus	Metered Over-All	Sample Over-All	Sample Combustion Efficiency %	Emission Indices g/kg fuel: CO	HC	NO_x	Engine NO_x	Eng. CO	SAE Smoke Number	Total Pressure Loss %	Average Exit Temperature K	Profile Factor	Pattern Factor	Notes[1]
493	601	2.94	430	13.9	694	7.6	18.1	.0138	0	.0138	.0199	99.1	37.6	0.5	3.5	-	-	-	4.84	956	-	-	
494	602	3.28	430	13.3	1622	6.7	16.0	.0162	.0175	.0337	.0356	96.9	64.1	15.7	2.6	-	-	-	-	1565	-	-	
495	603	3.10	431	13.6	1362	6.7	17.0	.0156	.0121	.0279	.0310	93.8	76.2	44.6	2.5	-	-	-	-	1367	-	-	
496	604	2.95	433	13.6	1117	7.1	17.8	.0158	.0071	.0229	.0274	91.9	82.4	62.2	2.4	-	-	-	-	1203	-	-	
497	605	2.94	431	13.9	541	7.0	18.1	.0108	0	.0108	.0147	99.5	16.5	1.2	3.1	-	-	-	-	852	-	-	
498	606	3.15	433	13.6	1381	6.5	16.9	.0114	.0168	.0282	.0302	95.7	70.9	26.7	2.1	-	-	-	-	1395	-	-	
499	607	2.96	433	13.7	1127	7.2	17.9	.0110	.0117	.0227	.0239	90.0	89.4	79.6	1.7	-	-	-	-	1183	-	-	
500	608	2.94	432	13.9	881	7.3	18.2	.0109	.0067	.0176	.0198	87.0	86.1	110.2	1.9	-	-	-	-	1009	-	-	
501	609	2.93	431	13.9	345	7.2	18.2	.0069	0	.0069	.0086	94.4	66.9	40.9	1.7	-	-	-	-	691	-	-	
502	610	3.01	433	13.6	1240	7.2	17.5	.0072	.0182	.0254	.0274	94.2	84.2	37.9	1.4	-	-	-	-	1301	-	-	
503	611	2.91	433	13.6	992	7.4	18.0	.0072	.0131	.0203	.0216	87.9	108.4	95.7	1.0	-	-	-	-	1088	-	-	
504	612	2.95	432	13.8	742	7.4	18.0	.0070	.0079	.0149	.0153	80.5	122.2	166.6	1.0	-	-	-	5.31	891	-	-	
505	701	3.44	516	15.6	782	7.0	20.7	.0140	0	.0140	.0201	99.4	25.2	0.4	4.2	-	-	-	5.35	1040	-	-	
506	702	3.74	516	15.3	1751	7.2	19.0	.0146	.0173	.0319	.0338	98.1	51.5	7.0	3.1	-	-	-	5.01	1597	-	-	
507	703	3.57	520	15.5	1480	7.9	20.1	.0143	.0123	.0266	.0293	96.5	67.6	19.1	3.1	-	-	-	5.44	1426	-	-	
508	704	3.44	519	15.7	1194	7.6	21.0	.0141	.0071	.0212	.0246	94.2	78.2	40.2	3.1	-	-	-	5.76	1242	-	-	
509	705	3.43	521	15.7	613	7.7	21.1	.0109	0	.0109	.0149	99.8	6.8	0.1	4.5	-	-	-	5.45	935	-	-	
510	706	3.65	520	15.5	1593	8.1	19.8	.0112	.0174	.0286	.0304	97.8	56.7	9.0	2.8	-	-	-	5.19	1498	-	-	
511	707	3.48	520	15.5	1315	8.1	20.5	.0112	.0124	.0236	.0248	94.9	81.2	31.7	2.6	-	-	-	5.61	1323	-	-	
512	708	3.40	517	15.6	1036	8.1	21.0	.0110	.0074	.0184	.0195	90.9	93.4	69.6	2.7	-	-	-	5.88	1133	-	-	
513	709	3.41	516	15.6	1032	7.8	21.0	.0109	.0074	.0183	.0181	80.5	81.8	176.3	3.2	-	-	-	5.51	1060	-	-	2,3
514	710	3.48	512	15.6	1309	8.0	20.4	.0110	.0123	.0233	.0259	95.5	72.6	28.3	2.7	-	-	-	5.65	1311	-	-	2
515	711	3.40	518	15.7	389	7.7	21.2	.0069	0	.0069	.0085	98.9	22.3	5.5	3.1	-	-	-	5.55	783	-	-	
516	712	3.61	520	15.5	1492	7.9	19.9	.0072	.0196	.0268	.0303	98.0	52.9	7.3	2.3	-	-	-	5.46	1447	-	-	
517	713	3.44	517	15.7	1212	8.1	20.8	.0070	.0145	.0215	.0239	95.1	87.8	28.8	1.7	-	-	-	5.96	1257	-	-	
518	714	3.39	518	15.7	948	8.0	21.2	.0071	.0096	.0167	.0183	89.7	113.4	76.9	1.6	-	-	-	6.00	1074	-	-	
519	801	3.40	623	13.8	691	8.0	22.6	.0139	0	.0139	.0204	99.5	21.4	0.2	6.7	-	-	-	5.20	1130	-	-	
520	802	3.50	624	13.7	1547	8.2	21.9	.0143	.0170	.0313	.0340	99.3	28.7	0.6	4.7	-	-	-	5.55	1671	-	-	
521	803	3.39	629	14.0	1297	8.4	23.0	.0140	.0118	.0258	.0297	98.5	49.5	3.9	4.8	-	-	-	5.83	1508	-	-	
522	804	3.41	628	14.0	1047	8.2	22.9	.0140	.0068	.0208	.0250	96.8	64.1	16.9	5.3	-	-	-	5.59	1343	-	-	
523	805	3.40	624	13.9	547	8.0	22.7	.0109	0	.0109	.0147	99.8	5.8	0.3	6.7	-	-	-	5.18	1030			
524	806	3.44	624	13.9	1426	7.6	22.5	.0118	.0167	.0285	.0295	99.2	30.0	1.0	4.0	-	-	-	5.68	1591			
525	807	3.40	627	14.0	1134	7.4	22.9	.0111	.0114	.0225	.0242	97.8	61.0	7.8	4.0	-	-	-	5.78	1402			
526	808	3.38	625	13.9	878	7.4	22.9	.0110	.0065	.0175	.0188	94.8	82.4	32.8	4.3	-	-	-	5.71	1225			
527	809	3.39	628	14.0	880	7.5	23.0	.0110	.0065	.0175	.0174	81.0	88.2	169.2	3.4	-	-	-	5.34	1138			2,3
528	810	3.39	628	14.0	1154	7.7	23.0	.0110	.0118	.0228	.0251	98.0	54.5	7.8	4.1	-	-	-	5.85	1414			2
529	811	3.40	628	14.0	348	7.5	23.0	.0069	0	.0069	.0076	99.8	5.1	1.3	5.9	-	-	-	5.24	890			
530	812	3.40	628	14.0	1298	7.9	22.9	.0071	.0187	.0258	.0279	99.2	29.8	1.2	3.3	-	-	-	5.89	1514			
531	813	3.40	628	14.0	1048	7.7	22.9	.0070	.0138	.0208	.0225	98.1	60.0	5.4	3.1	-	-	-	5.83	1354			
532	814	3.40	627	14.0	792	7.7	22.9	.0069	.0088	.0157	.0162	93.6	109.3	38.5	3.1	-	-	-	5.65	1161			

Notes:

1. Unless Otherwise Indicated, Single-position Sampling Mode
2. Twelve-position Sampling Mode
3. Before Crossfire to Inner Dome

Table XLVI. Summary of Test Results, Configuration D9.

Reading Number	Point Number	Inlet Total Pressure Atm	Inlet Total Temper-ature K	Combustor Airflow kg/sec	Total Fuel Flow kg/hr	Inlet Air Humidity g/kg Air	Reference Velocity m/sec	Fuel-Air Ratio g fuel / g air: Metered Outer Annulus	Metered Inner Annulus	Metered Over-All	Sample Over-All	Sample Combustion Efficiency %	Emission Indices g/kg fuel: CO	HC	NO_x	Engine NO_x	Engine CO	SAE Smoke Number	Total Pressure Loss %	Average Exit Temper-ature K	Profile Factor	Pattern Factor	Notes
548	100	2.91	429	13.7	0	-	18.0	0	0	0	0	-	-	-	-	-	-	-	4.67	429	-	-	
549	101	2.91	430	13.9	690	6.2	18.2	.0138	0	.0138	.0143	98.8	36.3	3.9	-	-	-	-	4.8[illegible]	954	1.36	0.88	
550	102	2.91	431	13.8	576	7.2	18.2	.0116	0	.0116	.0124	99.2	22.9	2.9	2.9	2.9	-	-	4.84	877	1.33	0.86	
551	103	2.91	431	13.8	547	7.2	18.2	.0110	0	.0110	.0112	99.2	21.2	3.0	3.2	3.2	-	1	4.84	858	1.33	1.02	1
579	103	2.91	431	13.7	542	8.1	18.0	.0110	0	.0110	.0124	99.4	19.2	1.6	3.4	3.4	-	-	4.80	858	1.34	0.92	
552	104	2.92	430	13.8	494	7.2	18.2	.0099	0	.0099	.0104	99.2	19.4	3.2	3.2	3.2	-	-	4.85	816	1.28	1.13	
553	105	2.93	430	13.8	396	7.2	18.2	.0080	0	.0080	.0[illegible]	98.4	33.0	8.8	2.5	2.5	-	-	4.74	741	1.29	1.26	
554	106	2.93	430	13.7	1411	7.5	17.2	.0113	.0173	.0286	.0324	95.7	68.0	27.2	2.1	-	-	-	4.75	1406	-	-	2
555	107	2.92	430	13.9	1158	7.5	18.2	.0111	.0121	.0232	.0251	90.3	89.2	76.1	1.7	-	-	-	5.24	1196	-	-	2
556	201	3.39	626	13.9	696	7.1	22.8	.0139	0	.0139	.0144	99.5	18.6	0.4	6.4	8.4	1.8	1	5.24	1134	1.32	0.59	1,4
562	206	3.38	632	13.9	694	7.1	23.0	.0112	.0027	.0139	.0149	94.5	72.5	38.2	5.1	9.4	52.2	-	5.35	1113	1.39	1.03	
567	226	3.41	631	13.7	693	7.3	22.5	.0113	.0028	.0141	.0150	96.6	53.4	21.8	5.5	10.1	35.8	-	5.10	1130	1.32	0.88	3
563	207	3.39	631	13.8	695	6.9	22.9	.0091	.0049	.0140	.0151	92.7	89.6	52.6	4.2	7.8	66.9	-	5.41	1105	1.31	1.06	
566	227	3.41	632	13.7	694	7.0	22.6	.0092	.0049	.0141	.0149	96.2	63.5	23.0	4.8	8.7	44.4	-	5.19	1130	1.27	0.71	3
564	208	3.40	631	13.8	697	7.0	22.8	.0071	.0069	.0140	.0149	91.8	112.5	55.7	3.4	6.3	88.4	-	5.36	1103	1.21	0.49	
565	228	3.40	631	13.7	694	7.2	22.7	.0072	.0068	.0140	.0148	95.9	68.3	25.5	3.9	7.1	48.6	-	5.2[illegible]	1123	1.17	0.56	3
557	202	3.46	631	13.8	1576	9.6	22.5	.0143	.0173	.0316	.0354	99.4	23.2	0.5	4.5	-	-	-	5.60	1688	-	-	2
558	203	3.40	630	13.9	1324	14.0	22.9	.0141	.0123	.0264	.03[illegible]	98.6	43.6	3.4	4.7	-	-	-	5.56	1531	-	-	2
559	209	3.40	631	13.9	547	11.7	22.9	.0109	0	.0109	.0144	99.9	5.5	0.2	6.9	-	-	-	5.19	1036	-	-	2
560	204	3.46	631	13.8	1543	10.8	22.4	.0113	.0198	.0311	.0348	99.5	18.3	0.5	4.2	-	-	-	5.65	1675	-	-	2
561	205	3.40	631	13.8	1287	7.7	22.8	.0111	.0147	.[illegible]258	.0295	99.1	31.0	1.7	3.8	-	-	-	5.70	1517	-	-	2
568	301	4.78	731	17.5	1314	8.2	23.8	.0032	.0177	.0209	.0237	99.5	18.6	0.3	4.7	7.5	10.3	-	5.11	1452	1.11	0.38	
569	302	4.76	731	17.4	1306	12.3	23.9	.0041	.0168	.0209	.0235	99.7	13.8	0.2	4.8	8.2	6.6	-	5.08	1452	1.12	0.36	
570	303	4.76	731	17.1	1308	8.7	23.6	.0062	.0150	.0212	.0234	99.7	12.4	0.3	5.6	8.8	5.6	-	5.03	1462	1.11	0.28	
572	401	4.76	784	17.1	1300	8.2	25.1	.0035	.0177	.0212	.0236	99.8	7.3	0.1	5.8	13.9	0.8	-	5.45	1508	1.12	0.39	
573	402	4.76	786	17.1	1285	8.9	25.1	.0041	.0164	.0210	.0238	99.9	5.4	0	6.0	14.5	0.3	1	5.32	1502	1.12	0.37	1
574	403	4.78	784	17.1	1304	8.2	25.0	.0060	.0153	.0213	.0239	99.9	3.9	0	7.0	16.9	0.1	-	5.24	1510	1.14	0.34	
575	501	4.76	818	16.9	1365	8.2	25.8	.0030	.0195	.0225	.0255	99.9	5.8	0	7.2	19.2	0.3	1	5.48	1575	1.13	0.37	1
576	502	4.76	819	17.0	1366	8.1	26.1	.0040	.0183	.0223	.0254	99.9	3.6	0	7.2	19.1	0.1	-	5.47	1570	1.13	0.38	
577	503	4.76	819	16.7	1363	8.8	25.7	.0060	.0167	.0227	.0253	99.9	2.5	0	8.0	21.2	0.1	-	5.29	1582	1.12	0.33	
578	504	4.76	819	16.7	1363	8.4	25.7	.0100	.0127	.0227	.0250	99.9	4.7	0	10.1	26.5	0.2	-	5.22	1581	1.17	0.31	

NOTES:

1. High Density Sampling Mode
2. Single Position Sampling Mode
3. Alternate Cups Fueled in Inner Annulus
4. Engine NO_x Calculated Using 0.2 Power of P_3

Table XLVII. Summary of Test Results, Configuration D10.

Reading Number	Point Number	Inlet Total Pressure Atm	Inlet Total Temperature K	Combustor Airflow kg/sec	Total Fuel Flow kg/hr	Inlet Air Humidity g/kg Air	Reference Velocity m/sec	Fuel-Air Ratio g fuel / g air: Metered Outer Annulus	Metered Inner Annulus	Metered Over-All	Sample Over-All	Sample Combustion Efficiency %	Emission Indices g/kg fuel: CO	HC	NO_x	Engine NO_x	Engine CO	SAE Smoke Number	Total Pressure Loss %	Average Exit Temperature K	Profile Factor	Pattern Factor	Notes
580	100	2.93	430	14.0	0	6.9	18.3	0	0	0	-	-	-			-	-	-	4.77	430	-	-	
581	101	2.91	431	14.0	688	10.6	18.3	.0137	0	.0137	.0166	99.1	32.5	2.0	2.8	3.0	-	-	4.85	953	1.31	0.95	
585	102	2.93	430	13.7	542	7.8	17.9	.0110	0	.0110	.0140	99.4	17.8	1.4	3.3	3.3	-	1	4.65	858	1.28	0.80	
582	103	2.91	431	13.9	492	10.3	18.3	.0098	0	.0098	.0110	99.4	15.0	2.4	2.9	3.1	-	-	4.82	814	1.28	0.82	
583	103	2.94	429	14.1	490	7.7	18.3	.0096	0	.0096	.0105	99.3	17.1	2.7	3.1	3.1	-	1	4.88	805	1.23	0.83	1
584	104	2.93	430	14.1	394	7.9	18.3	.0078	0	.0078	.0084	98.4	31.9	8.4	2.5	2.6	-	-	4.84	734	1.22	0.69	
597	201	3.40	633	14.0	787	8.0	23.0	.0157	0	.0157	.0183	99.3	29.7	0.5	6.9	8.9	5.5	1	5.07	1197	1.24	0.91	3
598	202	3.40	629	14.0	690	7.6	23.0	.0137	0	.0137	.0158	99.6	18.6	0.2	7.0	9.1	1.8	1	5.11	1125	1.24	0.99	1,3
599	203	3.40	629	13.9	593	7.7	22.9	.0118	0	.0118	.0138	99.8	9.4	0.1	7.1	9.2	0.8	-	5.13	1066	1.26	1.06	3
600	204	3.40	629	13.9	397	7.6	22.9	.0079	0	.0079	.0086	99.9	3.4	0.2	6.8	8.8	0.3	-	5.11	929	1.25	1.05	3
601	205	3.40	629	13.9	207	7.5	22.9	.0041	0	.0041	.0038	95.3	122.1	18.4	3.6	4.7	64.2	-	5.10	782	1.19	1.03	3
602	206	3.42	629	14.1	993	7.4	23.0	.0158	.0038	.0196	.0222	90.0	68.0	84.0	5.0	-	-	-	5.21	1259	1.24	0.88	
603	207	3.35	629	14.1	997	7.4	23.4	.0119	.0078	.0197	.0194	82.4	84.5	155.3	3.6	-	-	-	5.40	1207	1.26	0.92	
604	208	3.40	629	14.1	996	6.9	23.1	.0079	.0118	.0197	.0220	96.7	70.4	16.3	3.5	-	-	-	5.84	1308	1.14	0.27	
605	209	3.42	629	14.0	993	7.2	22.8	.0042	.0156	.0198	.0226	97.3	71.2	10.0	2.5	-	-	-	5.58	1315	1.13	0.42	
606	221	3.42	629	14.0	695	8.4	22.9	.0040	.0098	.0138	.0151	92.5	92.7	53.5	2.4	4.5	71.5	-	5.38	1097	1.13	0.90	2
607	222	3.40	629	14.0	691	7.4	22.9	.0070	.0068	.0138	.0147	95.4	65.5	30.5	3.8	7.1	47.0	-	5.29	1111	1.17	0.65	2
595	212	6.82	630	27.9	1425	8.4	22.9	.0069	.0073	.0142	.0161	96.7	49.6	21.8	5.0	6.7	41.6	1	5.33	1133	1.15	0.60	2
608	223	3.40	629	14.0	692	7.7	22.9	.0103	.0034	.0137	.0151	96.3	53.3	24.6	5.2	9.8	36.3	-	5.19	1115	1.25	0.87	2
596	213	6.82	630	27.9	1435	8.4	22.9	.0107	.0036	.0143	.0168	97.6	36.8	15.7	7.2	9.7	29.6	1	[illegible].08	1141	1.24	0.70	2
586	401	4.78	782	16.4	1293	8.0	24.4	.0042	.0177	.0219	.0236	99.8	10.2	0.1	6.2	14.5	1.8	-	-	1525	1.11	0.37	
587	402	4.79	782	17.3	1318	7.9	25.2	.0063	.0149	.0212	.0236	99.8	9.7	0.1	7.2	17.4	1.6	-	5.20	1504	1.10	0.32	
588	403	4.76	783	17.2	1293	7.9	25.2	.0080	.0129	.0209	.0232	99.6	14.2	0.3	7.9	19.2	3.5	-	5.16	1495	1.10	0.28	
589	404	4.77	786	17.2	1293	8.0	25.3	.0030	.0178	.0208	.0235	99.7	13.6	0.1	6.2	14.8	3.3	1	5.44	1497	1.11	0.45	1
590	501	4.77	819	16.6	1363	7.7	25.6	.0041	.0187	.0228	.0264	99.9	4.9	0	7.7	19.9	0.2	-	5.30	1585	1.13	0.40	
591	502	4.77	823	16.6	1366	7.7	25.6	.0061	.0167	.0228	.0261	99.9	4.0	0	8.6	21.9	0.1	-	5.28	1588	1.11	0.37	
592	503	4.76	824	16.5	1360	7.5	25.6	.0081	.0148	.0229	.0254	99.9	4.9	0	9.1	22.9	0.2	1	-	1593	1.10	0.32	
594	513	6.82	823	23.6	1946	6.1	25.4	.0080	.0149	.0229	.0266	99.9	3.3	0	11.6	23.6	0.2	1	5.16	1593	1.10	0.29	
593	504	4.78	820	16.7	1363	7.7	25.6	.0031	.0196	.0227	.0259	99.8	7.2	0	7.5	19.2	0.6	1	5.18	1581	1.12	0.41	1

Notes:

1. High Density Sampling Mode
2. Alternate Cups Fueled in Inner Annulus
3. Engine NO_x Calculated Using 0.2 Power of P_3

Table XLVIII. Summary of Test Results, Configuration D11.

Reading No.	Point No.	Inlet Total Press Atm	Inlet Total Temp K	Combustor Airflow kg/sec	Total Fuel Flow kg/hr	Inlet Air Humidity g/kg Air	Reference Velocity m/sec	Fuel-Air Ratio g fuel / g air, Metered: Outer Annulus	Metered: Inner Annulus	Metered: Over-all	Sample: Over-all	Sample Combustion Efficiency %	Emission Indices g/kg fuel: CO	HC	NO_x	Engine NO_x	Engine CO	SAE Smoke No.	Total Press Loss %	Average Exit Temp K	Profile Factor	Pattern Factor	Notes
609	100	2.90	430	13.8	0	-	18.3	0	0	0	0	-	-	-	-	-	-	-	4.55	430	-	-	
610	101	2.90	429	13.7	690	8.6	18.1	0.0139	0	0.0139	0.0160	98.8	39.9	2.6	2.8	3.0	-	-	4.85	958	1.58	1.01	
611	102	2.91	429	13.8	540	10.3	18.1	0.0109	0	0.0109	0.0119	99.3	20.1	2.5	2.9	3.2	-	1	4.74	850	1.53	1.04	1
612	103	2.91	429	13.7	492	9.8	18.0	0.0100	0	0.0100	0.0109	99.4	17.6	2.4	3.0	3.2	-	-	4.76	818	1.47	0.83	
613	104	2.92	429	13.6	392	9.5	17.9	0.0080	0	0.0080	0.0087	98.9	24.3	5.5	2.5	2.6	-	-	4.61	743	1.52	1.22	
614	201	3.42	626	13.8	689	8.2	22.5	0.0138	0	0.0138	0.0515	99.6	18.4	0.1	6.6	8.7	1.6	1	5.03	1132	1.51	1.07	1,3
617	202	3.40	624	13.9	686	8.5	22.6	0.0031	0.0106	0.0137	0.0145	97.4	54.8	12.8	3.0	5.9	36.9	1	5.39	1116	1.07	1.30	2,3
618	203	3.39	624	13.9	698	8.0	22.6	0.0070	0.0069	0.0139	0.0146	99.2	23.5	2.5	4.4	8.6	11.5	1	5.25	1131	1.20	0.91	2,3
636	213	6.80	626	27.7	1385	6.7	22.6	0.0070	0.0069	0.0139	0.0148	99.4	16.0	1.8	5.9	7.7	10.8	-	5.14	1134	1.21	0.86	2,3
619	204	3.40	630	13.7	689	8.0	22.6	0.0111	0.0028	0.0139	0.0149	97.5	47.7	14.2	5.7	10.8	30.8	1	5.34	1128	1.51	1.18	2,3
637	214	6.79	627	27.6	1385	7.0	22.7	0.0110	0.0029	0.0139	0.0148	98.1	36.2	10.7	7.8	10.3	29.0	-	5.18	1128	1.52	1.14	2,3
620	205	3.42	631	13.9	695	6.9	22.8	0.0112	0.0027	0.0139	0.0156	95.4	68.1	30.2	4.9	8.9	48.3	-	5.39	1118	1.54	1.03	
621	206	3.41	631	14.0	695	7.2	22.9	0.0070	0.0068	0.0138	0.0150	93.0	105.0	45.4	2.9	5.4	81.5	-	5.61	1103	1.32	0.61	
622	207	3.40	632	14.0	692	7.3	23.0	0.0031	0.0106	0.0137	0.0147	93.1	140.4	35.8	1.7	3.1	114.2	-	5.66	1101	1.07	0.40	
635	217	6.80	627	27.9	1387	3.4	22.8	0.0035	0.0103	0.0138	0.0154	95.2	114.9	21.2	3.5	4.3	104.1	-	5.38	1110	1.08	0.35	
623	208	3.41	632	13.8	684	7.7	22.9	0	0.0137	0.0137	0.0149	96.5	90.5	14.1	2.2	4.1	69.5	-	5.69	1116	1.12	0.43	
624	401	4.76	784	17.1	1309	6.8	25.1	0.0033	0.0180	0.0213	0.0238	99.9	4.6	0.1	6.4	15.1	0.2	-	5.25	1511	1.08	0.38	
625	402	4.76	788	16.9	1303	6.6	25.0	0.0042	0.0172	0.0214	0.0237	99.9	3.0	0.1	6.9	15.6	0.1	1	5.22	1519	1.08	0.39	1
626	403	4.78	789	17.0	1297	7.3	25.1	0.0061	0.0151	0.0212	0.0233	99.9	2.7	0.0	7.9	18.2	0.1	-	5.13	1512	1.08	0.27	
627	404	4.78	789	17.0	1299	7.1	25.0	0.0082	0.0130	0.0212	0.0232	99.9	4.5	0.1	8.8	20.1	0.2	-	5.11	1514	1.12	0.30	
628	405	4.78	789	17.1	1600	8.8	25.1	0.0041	0.0220	0.0261	0.0289	99.9	3.5	0.0	7.5	17.6	-	-	5.36	1659	1.10	0.37	
629	406	4.78	789	17.1	1001	8.6	25.2	0.0027	0.0136	0.0163	0.0180	99.6	17.8	0.2	6.2	14.5	-	-	5.15	1356	1.10	0.38	
630	501	4.78	827	16.6	1360	7.7	25.7	0.0031	0.0197	0.0228	0.0256	99.9	2.7	0.1	7.8	19.7	0.1	-	5.28	1592	1.10	0.40	
631	502	4.77	826	16.6	1363	9.2	25.6	0.0036	0.0193	0.0229	0.0259	100.0	2.3	0.0	8.0	20.4	0.1	1	5.22	1594	1.09	0.44	1
632	503	4.76	820	16.6	1371	8.3	25.6	0.0041	0.0188	0.0229	0.0258	100.0	1.9	0.0	8.0	20.7	0.1	-	5.19	1589	1.09	0.38	
633	504	4.79	819	16.6	1364	9.3	25.4	0.0062	0.0167	0.0229	0.0255	100.0	1.4	0.0	8.9	23.4	0.0	-	5.17	1588	1.08	0.29	
634	505	4.76	820	16.5	1364	8.5	25.4	0.0082	0.0148	0.0230	0.0256	100.0	1.5	0.0	9.6	25.0	0.0	-	5.08	1593	1.11	0.25	2

Notes:
1. High Density Sampling Mode
2. 15-Cup Sector Fueled in Inner Annulus
3. Engine NO_x Calculated Using 0.2 Power of P_3

Table XLIX. Summary of Test Results, Configuration D12A and D12B.

Reading No.	Point No.	Inlet Total Press Atm	Inlet Total Temp K	Combustor Airflow kg/sec	Total Fuel Flow kg/hr	Inlet Air Humidity g/kg Air	Reference Velocity m/sec	Fuel-Air Ratio g fuel / g air: Metered: Outer Annulus	Metered: Inner Annulus	Metered: Overall	Sample: Overall	Sample Combustion Efficiency %	Emission Indices g/kg fuel: CO	HC	NO_x	Engine NO_x	Engine CO	SAE Smoke No.	Total Press Loss %	Average Exit Temp K	Profile Factor	Pattern Factor	Notes
638	100	2.96	430	13.7	0	-	17.8	0	0	0	-	-	-	-	-	-	-	-	4.50	430	-	-	1
639	101	2.94	431	13.7	690	6.5	18.0	0.0140	0	0.0140	0.0162	98.3	46.0	6.1	3.3	3.2	-	2	4.70	958	1.51	1.30	1
640	102	2.93	432	13.8	571	7.4	18.0	0.0115	0	0.0115	0.0135	98.6	28.2	7.6	3.4	3.3	-	1	4.77	874	1.51	1.44	1
642	103	2.93	432	13.9	544	7.2	18.3	0.0109	0	0.0109	0.0127	98.7	24.5	7.3	3.3	3.3	-	1	4.72	851	1.48	1.16	1
643	104	2.93	432	13.9	490	7.3	18.2	0.0098	0	0.0098	0.0116	97.7	21.2	8.1	3.2	3.2	-	1	4.71	811	1.50	1.15	1
644	105	2.94	429	14.0	395	8.6	18.1	0.0079	0	0.0079	0.0092	97.9	30.3	14.1	2.6	2.7	-	1	4.62	734	1.49	1.22	1
645	106	2.95	428	12.8	544	8.9	16.9	0.0118	0	0.0118	0.0139	98.3	27.2	10.9	3.4	3.3	-	1	3.99	878	1.51	1.19	1
671	100	2.93	433	14.1	0	-	18.6	0	0	0	-	-	-	-	-	-	-	-	4.80	433	-	-	
672	101	2.94	430	13.9	699	10.4	18.1	0.0140	0	0.0140	0.0157	98.7	44.3	3.0	3.1	3.3	-	-	4.76	959	1.38	1.15	
673	102	2.94	430	13.9	553	9.6	18.1	0.0111	0	0.0111	0.0122	99.2	22.0	2.8	3.0	3.1	-	1	4.68	858	1.40	1.27	
674	103	2.93	431	13.9	504	9.1	18.2	0.0101	0	0.0101	0.0115	99.3	18.1	2.9	2.9	3.0	-	-	4.70	823	1.35	1.35	
675	104	2.95	430	13.9	405	8.7	18.1	0.0081	0	0.0081	0.0093	98.8	23.7	6.5	2.5	2.6	-	-	4.64	748	1.35	1.43	
696	105	2.91	429	13.8	301	7.3	18.0	0.0061	0	0.0061	0.0068	90.0	88.3	79.5	1.1	1.1	-	-	4.60	649	1.37	1.35	
691	121	2.92	431	13.8	1001	7.6	18.0	0.0161	0.0039	0.0200	0.0231	87.5	83.0	106.0	1.7	-	-	-	4.76	1083	1.34	0.93	
692	122	2.92	430	13.7	1004	9.1	18.1	0.0123	0.0080	0.0203	-	76.4	-	-	-	-	-	-	-	1026	1.35	1.05	2
693	123	2.92	430	13.8	1001	8.6	18.1	0.0103	0.0098	0.0201	-	68.2	-	-	-	-	-	-	-	963	1.36	1.05	2
694	124	2.92	429	13.6	1007	8.1	17.8	0.0084	0.0123	0.0207	0.0227	88.8	94.6	90.0	0.8	-	-	-	5.02	1110	1.22	0.58	
695	125	2.93	429	13.7	997	7.6	18.0	0.0042	0.0160	0.0202	0.0206	80.0	114.0	173.0	0.4	-	-	-	5.15	1030	1.15	0.61	
676	201	3.41	622	13.7	705	9.8	22.3	0.0143	0	0.0143	0.0160	99.4	24.7	0.3	6.5	9.0	3.4	1	4.90	1143	1.30	1.05	3,5
685	212	6.78	629	27.6	1402	6.7	22.8	0.0112	0.0029	0.0141	0.0152	97.7	40.3	13.8	7.6	10.0	32.8	3	5.02	1135	1.33	1.04	4
684	213	6.80	629	27.5	1403	7.0	22.7	0.0092	0.0050	0.0142	0.0152	98.5	37.4	6.6	6.7	8.8	30.1	2	5.02	1140	1.26	0.86	4
683	214	6.77	629	27.5	1407	6.9	22.8	0.0072	0.0070	0.0142	0.0155	99.3	20.9	2.7	5.9	7.8	15.1	2	5.10	1145	1.20	1.02	4
682	215	6.75	627	27.4	1408	6.4	22.7	0.0057	0.0086	0.0143	0.0162	99.4	16.0	2.4	5.3	7.0	10.8	3	5.10	1147	1.12	1.16	4
677	401	4.76	784	17.2	1318	4.0	25.3	0.0031	0.0182	0.0213	0.0238	99.8	7.2	0.2	6.5	14.6	0.8	-	5.21	1509	1.09	0.33	
678	402	4.77	785	17.0	1317	4.9	25.0	0.0041	0.0174	0.0215	0.0236	99.9	4.6	0.2	6.6	14.8	0.2	-	5.16	1518	1.10	0.36	
679	403	4.77	785	17.1	1320	6.9	25.1	0.0062	0.0153	0.0215	0.0233	99.9	4.0	0.2	7.5	17.4	0.2	-	5.07	1519	1.10	0.34	
680	404	4.76	785	16.9	1318	13.0	25.0	0.0083	0.0133	0.0216	0.0229	99.8	6.5	0.2	8.4	21.8	0.7	-	5.00	1521	1.13	0.34	
681	405	4.76	785	17.0	1319	8.8	25.1	0.0025	0.0191	0.0216	0.0236	99.8	8.9	0.2	6.5	15.8	1.4	1	5.13	1519	1.11	0.41	
686	501	4.77	816	16.3	1384	9.0	25.1	0.0032	0.0204	0.0236	0.0262	99.9	4.4	0.4	7.6	19.9	0.2	-	5.02	1605	1.12	0.41	
687	502	4.77	818	16.3	1383	8.8	25.1	0.0042	0.0194	0.0236	0.0260	99.9	2.9	0.1	7.5	19.6	0.1	-	5.02	1609	1.10	0.35	
688	503	4.78	818	16.5	1384	9.8	25.4	0.0062	0.0172	0.0234	0.0259	100.0	2.0	0.1	8.4	22.5	0.1	-	4.98	1601	1.11	0.35	
689	504	4.78	816	16.5	1387	9.2	25.3	0.0082	0.0152	0.0234	0.0256	100.0	2.1	0.0	9.4	24.9	0.1	-	4.92	1601	1.12	0.35	
690	505	4.78	817	16.5	1383	10.0	25.3	0.0036	0.0197	0.0233	0.0261	99.9	3.3	0.0	7.5	20.1	0.1	1	5.05	1598	1.12	0.38	

Notes:

1. Engine Prototype Pilot Stage Fuel Nozzles (Configuration 12A)
2. Gas Samples Not Taken; Efficiency Determined from Exit Temperature Thermocouple Data
3. High Density Sampling Mode
4. 15-Cup Sector Fueled in Inner Annulus
5. Engine NO_x Calculated Using 0.2 Power of P_3

Table L. Summary of Sea Level Ignition Test Results, Configuration D12A.

Point Number	Inlet Total Pressure atm	Inlet Total Temperature K	Combustor Airflow kg/s	Type Ignitor	Required Fuel Flows (kg/hr) Lightoff	50% Propagation	100% Propagation	50% Cups Out	Lean Blowout
61	1.00	315	2.72	spark	208	208	219	133	-
					206	211	217	122	91
					202	202	214	152	88
					205	-	-	-	-
71	1.01	309	3.31	spark	220	-	-	128	8
							-	-	35
81	1.01	315	3.63	spark	217	222	-	173	55
					231	-	249	161	39
					217	230	244	161	28
					222	229	247	163	48
					226	-	-	-	-
101	1.03	310	4.81	spark	-	-	-	217	90
120	1.04	319	5.49	spark	231	252	254	-	106
					230	248	253	213	118
					254	-	277	227	117

Notes:

a. JP-5 at 302 K

b. Barometric pressure =.990 atmospheres

Table LI. Summary of Sea Level Efficiency Test Results, Configuration D12A.

Point Number	Inlet Total Pressure atm	Inlet Total Temperature K	Combustor Airflow kg/s	Metered Fuel-Air Ratio g Fuel/g Air	Measured Temperature Rise K	Combustor Efficiency %
63	1.01	314	2.69	.0233	643	69.6
64	1.01	312	2.67	.0280	793	74.2
82	1.02	316	3.67	.0204	591	73.6
83	1.02	316	3.69	.0238	689	74.8
84	1.02	316	3.64	.0277	767	72.1
121	1.05	316	5.51	.0184	597	82.3
122	1.05	315	5.50	.0206	656	82.2
123	1.06	315	5.51	.0229	714	80.8

Notes:

a. JP-5 at 302 K

b. Barometric pressure = .990 atmospheres

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Table LII. Summary of Test Results, Configuration D13.

Reading No.	Point No.	Inlet Total Press Atm	Inlet Total Temp K	Combustor Airflow kg/sec	Total Fuel Flow kg/hr	Inlet Air Humidity g/kg Air	Reference Velocity m/sec	Fuel-Air Ratio g fuel / g air: Metered Outer Annulus	Metered Inner Annulus	Metered Overall	Sample Overall	Sample Combustion Efficiency %	Emission Indices g/kg fuel: CO	HC	NO_x	Engine NO_x	Engine CO	SAE Smoke No.	Total Press Loss %	Average Exit Temp K	Profile Factor	Pattern Factor	Notes
697	100	2.96	432	13.9	0	-	18.3	0	0	0	-	-	-	-	-	-	-	-	4.86	432	-	-	
717	101	2.95	436	13.9	700	12.9	18.3	0.0140	0	0.0140	0.0176	98.6	49.7	2.6	2.9	3.0	-	-	5.07	965	-	-	1
698	102	2.93	432	14.0	571	6.4	18.3	0.0113	0	0.0113	0.0125	99.4	19.0	2.0	3.4	3.3	-	-	5.03	869	1.48	1.19	
718	103	2.91	432	13.8	497	12.6	18.3	0.0100	0	0.0100	0.0119	99.2	21.8	3.0	2.5	2.8	-	-	4.99	821	-	-	1
719	104	2.92	433	13.4	402	12.1	18.3	0.0083	0	0.0083	0.0093	98.5	32.3	7.8	2.0	2.3	-	-	4.93	756	-	-	1
712	201	3.45	630	13.9	701	12.9	22.6	0.0140	0	0.0140	0.0166	99.4	23.4	0.1	6.3	8.8	3.1	-	5.00	1139	1.55	1.16	2
713	202	3.43	629	13.7	601	13.0	22.5	0.0122	0	0.0122	0.0146	99.7	11.8	0.1	6.3	8.9	1.0	-	5.06	1078	1.56	1.14	2
705	212	6.84	628	28.0	1186	3.9	22.9	0.0118	0	0.0118	0.0147	99.9	5.2	0.1	8.3	8.8	1.8	-	5.20	1064	1.55	1.20	2
714	203	3.44	628	13.8	499	13.0	22.5	0.0101	0	0.0101	0.0110	99.9	4.1	0.1	6.6	9.4	0.4	-	5.02	1004	1.64	1.37	2
706	213	6.82	628	28.2	997	3.1	23.1	0.0098	0	0.0098	0.0122	99.9	2.3	0.1	8.2	8.7	0.8	-	5.21	995	1.56	1.27	2
715	204	3.43	632	13.8	401	11.9	22.6	0.0081	0	0.0081	0.0089	99.9	2.7	0.1	6.6	9.0	0.2	-	5.19	937	-	-	1, 2
707	214	6.82	627	28.1	791	5.2	22.9	0.0078	0	0.0078	0.0093	99.9	2.3	0.4	7.9	8.7	0.8	-	5.09	924	1.56	1.29	2
716	205	3.42	631	13.8	303	12.2	22.7	0.0061	0	0.0061	0.0070	99.7	11.7	0.7	4.1	5.6	1.0	-	5.18	865	-	-	1, 2
708	215	6.84	628	27.9	590	10.4	22.8	0.0059	0	0.0059	0.0068	99.6	10.4	1.5	7.2	8.7	3.6	-	5.23	852	1.54	1.21	2
702	216	6.80	627	27.8	1403	9.3	22.8	0.0030	0.0110	0.0140	0.0157	97.6	47.7	12.8	4.3	6.0	39.8	-	5.41	1130	1.24	1.40	3
703	217	6.82	627	27.8	1407	8.4	22.8	0.0060	0.0081	0.0141	0.0157	99.2	16.8	4.1	4.6	6.2	11.5	-	5.38	1139	1.17	0.98	3
704	218	6.83	629	28.0	1399	10.1	22.9	0.0085	0.0054	0.0139	0.0157	98.9	28.5	4.4	5.7	8.0	22.0	-	5.36	1133	1.28	0.75	3
742	401	4.72	784	17.2	1299	10.9	25.3	0.0030	0.0180	0.0210	0.0240	99.7	10.7	0.1	5.3	13.7	2.1	-	5.67	1499	1.20	0.40	4
743	402	4.74	786	17.1	1306	9.9	25.2	0.0041	0.0171	0.0212	0.0242	99.9	5.5	0.0	5.3	13.1	0.4	-	5.66	1509	1.19	0.41	
744	403	4.75	786	17.0	1300	9.0	25.1	0.0061	0.0151	0.0212	0.0239	99.9	4.4	0.0	6.1	14.8	0.2	-	5.59	1510	1.14	0.36	
745	404	4.73	786	17.0	1305	10.6	25.1	0.0082	0.0132	0.0214	0.0239	99.8	7.0	0.1	6.9	17.2	0.8	-	5.34	1515	1.11	0.28	
748	501	4.72	820	16.5	1387	11.4	25.5	0.0038	0.0196	0.0234	0.0262	99.9	4.9	0.0	6.9	19.1	0.2	-	5.44	1604	1.21	0.43	
723	511	9.53	816	33.3	2756	9.2	25.5	0.0035	0.0195	0.0230	0.0274	100.0	2.2	0.0	9.6	18.3	0.2	-	5.38	1589	1.17	0.38	
721	502	4.77	821	16.6	1195	13.8	25.6	0.0036	0.0164	0.0200	0.0219	99.9	5.2	0.0	5.6	16.0	0.3	-	5.38	1502	1.16	0.33	
726	512	9.53	820	33.1	2373	9.0	25.5	0.0035	0.0164	0.0199	0.0235	100.0	3.4	0.0	8.4	15.5	0.3	-	5.43	1499	1.21	0.43	
700	512	9.74	819	32.3	2280	9.7	24.6	0.0036	0.0160	0.0196	0.0230	99.9	3.1	0.1	8.5	15.4	0.3	-	-	1489	-	-	
710	503	4.77	815	16.6	1017	14.1	25.5	0.0036	0.0134	0.0170	0.0194	99.7	11.0	0.1	5.4	16.1	2.0	-	5.21	1401	1.14	0.31	
727	513	9.53	820	33.1	2021	8.7	25.5	0.0035	0.0135	0.0170	0.0201	99.8	7.5	0.0	8.7	16.0	1.8	-	5.24	1405	1.19	0.38	
709	504	4.84	816	17.0	833	10.4	25.6	0.0035	0.0101	0.0136	0.0160	99.1	34.8	0.8	5.5	15.2	16.3	-	5.18	1291	1.10	0.31	
728	514	9.53	820	33.1	1667	8.4	25.6	0.0035	0.0105	0.0140	0.0164	99.3	27.8	0.5	8.7	16.1	15.9	-	5.52	1599	1.27	0.51	
749	505	4.76	820	16.6	1393	8.9	25.6	0.0025	0.0208	0.0233	0.0266	99.8	8.2	0.0	7.1	18.7	1.0	-	5.21	1587	1.21	0.42	
699	515	9.55	819	33.4	2752	9.0	25.6	0.0025	0.0204	0.0229	0.0270	99.9	4.2	0.2	9.0	16.8	0.5	-	5.43	1610	1.19	0.43	
747	506	4.75	824	16.5	1394	10.7	25.6	0.0047	0.0188	0.0235	0.0266	99.9	3.4	0.0	6.8	18.0	0.1	-	5.31	1595	1.15	0.37	
724	516	9.53	817	32.9	2741	9.4	25.4	0.0045	0.0186	0.0231	0.0270	100.0	1.4	0.0	9.7	18.3	0.1	-	5.54	1604	1.16	0.36	
746	507	4.73	825	16.6	1388	12.0	25.8	0.0062	0.0170	0.0232	0.0260	99.9	2.4	0.0	7.3	20.0	0.1	-	5.22	1588	1.16	0.32	
725	517	9.54	818	33.2	2739	8.8	25.5	0.0060	0.0169	0.0229	0.0267	100.0	1.0	0.0	10.2	19.1	0.1	-	5.12	1584	1.15	0.32	
701	557	6.83	815	23.9	1967	8.4	25.5	0.0060	0.0168	0.0228	0.0267	100.0	1.4	0.0	9.2	20.4	0.1	-	5.32	1599	-	-	
750	567	2.72	820	9.4	791	9.3	25.4	0.0063	0.0169	0.0232	0.0256	99.9	5.2	0.0	5.6	19.4	0.1	-					

Notes:

1. Single Position Sampling Mode
2. Engine NO_x Calculated Using 0.2 Power of P_3
3. 15 Cup Sector Fueled in Inner Annulus
4. High Density Sampling Mode

Table LIII. Summary of Test Results, Configuration D13 (DOT).

Reading Number	Point Number	Inlet Total Pressure Atm	Inlet Total Temperature K	Combustor Airflow kg/sec	Total Fuel Flow kg/hr	Inlet Air Humidity g/kg Air	Reference Velocity m/sec	Fuel-Air Ratio g fuel/g air: Metered			Sample	Sample Combustion Efficiency %	Emission Indices g/kg fuel					SAE Smoke Number	Total Pressure Loss %	Average Exit Temperature K	Profile Factor	Pattern Factor	Notes (1)
								Outer Annulus	Inner Annulus	Overall	Overall		CO	HC	NO_x	Engine NO_x	Engine CO						
764	1	2.37	555	9.2	782	5.6	19.3	.0060	.0177	.0237	.0271	96.8	66.9	16.2	1.6	-	-	-	4.62	1371	-	-	
765	2	2.38	816	9.1	780	5.5	27.5	.0061	.0177	.0238	.0263	99.8	6.6	0.3	4.4	-	-	-	6.66	1613	-	-	
753	3	4.75	817	18.1	795	10.0	26.5	.0032	.0090	.0122	.0141	98.1	72.7	2.2	5.2	-	-	-	6.18	1241	-	-	2
766	4	2.87	819	9.2	788	4.5	23.9	.0061	.0177	.0238	.0258	99.9	3.7	0.2	6.1	-	-	-	4.73	1615	-	-	
767	5	2.86	820	11.0	954	7.0	28.0	.0061	.0179	.0240	.0262	99.9	5.0	0.2	4.9	-	-	-	6.74	1622	-	-	
763	6	3.89	555	18.4	1587	9.4	23.1	.0061	.0178	.0239	.0269	97.6	61.0	10.3	1.8	-	-	-	6.89	1384	-	-	
762	7	4.74	554	18.2	1579	8.5	19.3	.0061	.0180	.0241	.0280	98.8	39.2	3.1	2.7	-	-	-	4.43	1400	-	-	
752	9	4.76	816	18.2	1590	8.7	26.6	.0063	.0180	.0243	.0280	99.9	3.1	0	6.6	-	-	-	6.36	1627	-	-	2
751	10	4.75	817	14.9	1292	7.9	23.2	.0063	.0179	.0242	.0276	99.9	2.4	0	8.0	-	-	-	4.36	1624	-	-	
754	11	5.79	818	18.1	1589	8.7	23.3	.0062	.0181	.0243	.0270	100.0	2.3	0	9.3	-	-	-	4.37	2201	-	-	
761	12	7.84	380	36.5	3146	9.5	16.0	.0085	.0155	.0240	.0279	93.3	74.5	49.7	1.8	-	-	-	4.47	1205	-	-	
759	13	7.87	555	36.4	3151	10.6	22.7	.0061	.0179	.0240	.0277	98.8	40.6	3.0	2.6	-	-	-	6.50	1398	-	-	
760	14	7.86	556	30.1	2599	9.3	19.3	.0061	.0179	.0240	.0282	99.2	28.3	1.5	3.4	-	-	-	4.40	1401	-	-	
757	15	9.51	556	36.1	3154	10.0	19.2	.0062	.0181	.0243	.0280	99.4	23.0	1.0	3.7	-	-	-	4.31	1412	-	-	
758	16	9.52	554	41.0	3540	10.4	20.4	.0062	.0178	.0240	.0274	99.0	33.8	1.9	3.3	-	-	-	5.49	1397	-	-	2
755	17	9.52	817	36.2	3157	9.4	27.4	.0062	.0180	.0242	.0273	100.0	1.3	0	9.6	-	-	-	6.34	1627	-	-	
756	18	9.56	817	36.3	1578	8.4	27.5	.0031	.0090	.0121	.0138	98.5	55.9	1.8	7.6	-	-	-	6.14	1238	-	-	

Notes:

1. Single position sampling mode
2. Bleed airflow less than design

Table LIV. Summary of Test Results, Configuration D14A.

Reading No.	Point No.	Inlet Total Press Atm	Inlet Total Temp K	Combustor Airflow kg/sec	Total Fuel Flo kg/hr	Inlet Air Humidity g/kg Air	Reference Velocity m/sec	Fuel-Air Ratio g fuel / g air: Metered Outer Annulus	Metered Inner Annulus	Metered Overall	Sample Overall	Sample Combustion Efficiency %	Emission Indices g/kg fuel: CO	HC	NO_x	Engine NO_x	Engine CO	SAE Smoke No.	Total Press Loss %	Average Exit Temp K	Profile Factor	Pattern Factor	Notes
768	100	2.97	433	13.8	0	4.4	18.0	0	0	0	0	-	-	-	-	-	-	-	4.42	433	-	-	
787	101	2.93	432	13.8	704	9.7	18.1	0.0141	0	0.0141	0.0147	98.6	45.9	3.3	[illegible]	3.1	-	-	4.59	966	1.48	1.07	
769	102	2.91	430	13.8	561	6.6	18.2	0.0113	0	0.0113	0.0136	99.1	26.4	3.1	2.6	2.6	-	0	4.62	864	1.37	1.16	
788	102	2.91	423	13.8	557	9.7	17.9	0.0112	0	0.0112	0.0117	99.0	28.2	3.7	2.8	3.0	-	1	4.48	855	1.45	1.10	
789	103	2.93	428	13.9	501	8.8	17.9	0.0100	0	0.0100	0.0105	98.9	26.8	4.5	2.8	2.9	-	-	4.41	816	1.45	1.13	
790	104	2.93	430	13.9	403	9.4	18.1	0.0081	0	0.0081	0.0083	98.3	34.8	9.2	2.6	2.7	-	-	4.46	745	1.40	1.16	
782	201	3.41	628	13.8	710	8.0	22.6	0.0143	0	0.0143	0.0152	99.4	24.4	0.8	5.9	7.7	3.4	1	4.77	[illegible]	1.47	1.15	1
783	202	3.41	628	13.7	608	8.6	22.5	0.0123	0	0.0123	0.0132	99.7	12.5	0.4	6.4	8.4	1.1	-	4.72	1080	1.46	1.10	1
800	212	6.80	626	27.7	1213	6.3	22.7	0.0122	0	0.0122	0.0132	99.8	7.1	0.3	7.9	8.8	2.4	0	4.76	1075	1.50	1.35	1
784	203	3.40	628	13.8	505	9.2	22.6	0.0102	0	0.0102	0.0104	99.8	6.1	0.3	6.9	9.3	0.5	-	4.73	1008	1.47	1.19	1
801	213	6.81	629	27.8	1008	7.3	22.8	0.0101	0	0.0101	0.0110	99.9	3.1	0.2	8.0	9.0	1.1	0	4.71	1006	1.50	1.38	1
785	204	3.40	627	13.7	406	8.4	22.6	0.0082	0	0.0082	0.0083	99.9	3.5	0.3	7.5	9.9	0.3	-	4.75	938	1.44	1.07	1
802	214	6.82	629	26.7	807	6.7	22.7	0.0081	0	0.0081	0.0087	99.9	2.0	0.2	8.0	8.8	0.7	-	4.73	936	1.53	1.44	1
786	205	3.40	627	13.7	305	9.7	22.6	0.0062	0	0.0062	0.0062	99.8	7.4	0.7	5.6	7.6	0.6	-	4.79	863	1.44	1.19	1
803	215	6.81	629	27.9	606	-	22.8	0.0060	0	0.0060	0.0065	99.8	6.1	0.4	7.4	8.2	2.0	-	4.76	860	[illegible]	1.33	1
797	216	6.80	628	27.8	1412	6.5	22.8	0.0031	0.0110	0.0141	0.0161	95.4	101.1	22.0	3.5	4.3	90.8	-	5.17	1121	1.16	0.58	
798	217	6.80	628	27.9	1419	6.5	22.8	0.0062	0.0080	0.0142	0.0159	95.1	87.7	28.5	4.9	6.5	77.9	-	5.12	1121	1.16	0.58	
799	218	6.80	625	27.9	1417	6.9	22.7	0.0091	0.0050	0.0141	0.0155	94.4	71.5	39.4	5.7	7.6	62.3	-	5.06	1115	1.41	0.89	
779	301	4.76	726	17.6	1355	9.0	24.0	0.0031	0.0183	0.0214	0.0243	99.6	16.4	0.4	5.1	8.6	8.8	-	4.99	1464	1.19	0.51	
780	302	4.76	727	17.6	1355	9.6	24.1	0.0042	0.0171	0.0213	0.0240	99.7	11.5	0.2	5.2	8.7	5.2	1	4.98	1463	1.17	0.50	
804	303	4.78	731	17.6	1349	8.8	24.0	0.0062	0.0151	0.0213	0.0237	99.7	10.7	0.2	6.2	10.1	4.6	-	4.88	1467	1.13	0.50	
805	304	4.78	734	17.5	1351	9.3	24.0	0.0083	0.0131	0.0214	0.0239	99.6	13.9	0.4	7.0	11.2	6.9	-	4.86	1471	1.11	0.56	
775	411	9.51	784	34.1	2656	5.9	25.2	0.0031	0.0185	0.0216	0.0254	99.9	4.4	0.0	10.4	17.0	0.7	-	4.98	1522	1.18	0.47	
776	412	9.53	785	34.1	2654	6.7	25.1	0.0041	0.0176	0.0217	0.0252	99.9	3.0	0.0	10.7	17.6	0.4	1	4.95	1523	1.16	0.45	
777	413	9.54	785	34.1	2663	6.1	25.1	0.0062	0.0155	0.0217	0.0250	99.9	2.4	0.0	11.8	19.2	[illegible]	-	4.86	1525	1.11	0.40	
778	414	9.53	786	33.9	2649	6.9	25.0	0.0025	0.0192	0.0217	0.0254	99.9	6.0	0.1	10.4	17.1	1.4	-	5.02	1525	1.20	0.50	
793	511	9.56	818	33.0	2779	6.7	25.3	0.0021	0.0213	0.0234	0.0275	99.8	6.4	0.2	12.2	21.8	1.3	-	4.85	1574	1.17	0.58	
794	512	9.60	822	33.0	2780	8.0	25.3	0.0031	0.0203	0.0234	0.0270	99.9	4.3	0.1	12.1	21.5	0.5	0	4.86	1590	1.18	0.57	2
795	513	9.54	821	32.7	2779	6.1	25.2	0.0042	0.0194	0.0236	0.0274	99.9	2.4	0.1	12.5	21.6	0.2	-	4.78	1611	1.16	0.52	
796	514	9.53	821	32.7	2767	5.6	25.3	0.0063	0.0172	0.0235	0.0269	100.0	1.9	0.1	13.4	22.9	0.2	-	4.75	1609	1.11	0.44	

Notes:

1. Engine NO_x Calculated Using 0.2 Power of P_3
2. High Density Sampling Mode

Table LV. Altitude Relight Test Results. Configuration D14B.

Rdg. No.	Simulated Flight Condition		Combustor Operating Conditions						Lightoff Attempt		
	Alt. km	M_p	T_F K	T_3 K	P_3 atm	W_c kg/s	$\frac{\Delta P}{P}$ %	$\frac{PT}{V}$ $\frac{atm-K}{m/s}$	W_f kg/hr	f	Light Off
809	4.9	.33	303	304	.551	1.32	–	30.4	249	.0524	Yes
810	6.5	.36	302	304	.449	1.32	–	19.8	249	.0524	Yes
811	7.7	.39	302	303	.381	1.34	–	14.2	249	.0516	Yes
812	8.8	.42	301	303	.327	1.34	–	10.5	249	.0516	Yes
816	8.7	.55	299	299	.395	2.36	–	8.7	249	.0293	Yes
813	6.7	.58	300	300	.531	3.37	–	11.0	249	.0205	Yes
814	7.9	.63	299	300	.476	3.54	–	8.4	249	.0195	Yes
815	8.4	.65	299	299	.456	3.31	–	8.3	249	.0209	Yes
820	1.8	.54	298	298	.966	5.44	–	22.6	249	.0127	Yes
818	8.2	.87	298	298	.687	5.53	–	11.2	249	.0125	Yes
819	9.9	.95	298	298	.646	5.49	–	10.0	249	.0126	Yes
817	10.1	.61	298	299	.333	2.36	–	6.2	390	.0459	No
814A	9.6	.71	299	300	.408	3.40	–	6.4	249	.0203	No

Table LVI. Summary of Test Results, Configuration D14B.

Reading Number	Point Number	Inlet Total Pressure Atm	Inlet Total Temperature K	Combustor Airflow kg/sec	Total Fuel Flow kg/hr	Inlet Air Humidity g/kg Air	Reference Velocity m/sec	Fuel-Air Ratio g fuel / g air: Metered: Outer Annulus	Metered: Inner Annulus	Metered: Overall	Sample: Overall	Sample Combustion Efficiency %	Emission Indices g/kg fuel: CO	HC	NO_x	Engine NO_x	Engine CO	SAE Smoke No.	Total Pressure Loss %	Average Exit Temperature K	Profile Factor	Pattern Factor	Notes
821	100	2.91	425	13.8	0	-	18.0	0	0	0	-	-	-	-	-	-	-	-	4.19	425	-	-	
836	101	2.92	428	13.5	709	9.4	17.7	0.0146	0	0.0146	0.0147	96.7	77.1	14.7	2.9	3.0	-	-	4.03	968	1.67	1.40	
837	102	2.93	427	13.7	549	[illegible]	17.9	0.0112	0	0.0112	0.0120	97.0	48.4	18.8	3.1	3.2	-	1	4.08	849	1.66	1.68	1
838	103	2.93	426	13.7	506	8.5	17.8	0.0102	0	0.0102	0.0098	96.8	43.7	21.7	3.0	3.1	-	-	4.05	815	1.67	1.67	
839	104	2.91	428	13.7	404	8.7	17.9	0.0082	0	0.0082	0.0078	95.8	49.3	31.0	2.7	2.8	-	-	4.05	740	1.70	1.72	
840	105	2.91	428	16.1	655	8.6	20.6	0.0112	0	0.0112	0.0109	97.6	54.6	11.7	2.8	3.3	-	-	5.65	854	1.66	1.70	
831	201	3.40	628	13.9	708	9.5	22.7	0.0142	0	0.0142	0.0149	99.2	34.2	0.3	6.1	8.3	7.1	1	4.50	1140	1.61	1.30	1, 2
832	202	3.41	628	13.8	601	8.5	22.6	0.0121	0	0.0121	0.0117	99.5	18.3	0.3	6.4	8.4	1.6	0	4.45	1063	1.59	1.29	2
833	203	3.40	629	13.9	504	8.6	22.8	0.0101	0	0.0101	0.0097	99.8	9.2	0.3	6.8	9.0	0.8	-	4.37	1005	1.69	1.46	2
834	204	3.40	629	13.8	401	8.7	22.7	0.0081	0	0.0081	0.0077	99.9	4.7	0.3	7.2	9.5	0.4	-	4.42	933	1.66	1.39	2
835	205	3.41	629	13.8	304	[illegible]	22.6	0.0061	0	0.0061	0.0058	99.7	10.6	1.0	5.9	7.8	0.9	-	4.35	863	1.68	1.39	2
830	221	5.08	630	20.5	1062	[illegible]	22.6	0.0144	0	0.0144	0.0142	99.5	22.6	0.1	7.4	8.7	5.5	1	4.44	1155	1.68	1.23	2
829	222	5.09	630	20.5	907	7.2	22.7	0.0123	0	0.0123	0.0122	99.7	12.9	0.1	7.7	9.0	2.4	0	4.29	1082	1.67	1.31	2
828	223	5.09	630	20.5	757	7.5	22.6	0.0102	0	0.0102	0.0102	99.9	6.4	0.1	8.0	9.4	1.2	-	4.25	1012	1.68	1.37	2
826	224	5.09	630	20.6	606	7.8	22.8	0.0082	0	0.0082	0.0081	99.9	3.4	0.1	7.9	9.4	0.6	-	4.33	938	1.76	1.25	2
827	225	5.09	626	20.6	457	7.4	22.5	0.0062	0	0.0062	0.0061	99.8	7.6	0.6	7.2	8.6	1.4	-	4.30	861	1.69	1.26	2
822	212	6.77	626	27.2	1218	7.9	22.4	0.0125	0	0.0125	0.0138	99.7	10.3	0.2	8.1	9.1	3.4	1	4.30	1086	1.62	1.45	2
823	213	6.78	626	27.1	1007	8.6	22.3	0.0103	0	0.0103	0.0114	99.9	4.7	0.1	8.3	9.6	1.6	-	4.23	1012	1.61	1.38	2
824	214	6.78	629	27.0	805	7.9	22.4	0.0083	0	0.0083	0.0089	99.9	2.5	0.2	8.3	9.4	0.9	-	4.19	941	1.66	1.38	2
825	215	6.79	630	27.4	603	8.2	22.7	0.0061	0	0.0061	0.0064	99.8	6.4	0.6	7.9	8.9	2.2	-	4.29	863	1.86	1.24	2

Notes:
1. High Density Sampling Mode.
2. Engine NO_x Calculated using 0.2 Power of P_3.

Table LVII. Summary of Test Results, Configuration R1.

Reading Number	Point Number	Inlet Total Pressure Atm	Inlet Total Temperature K	Combustor Airflow kg/sec	Total Fuel Flow kg/hr	Inlet Air Humidity g/kg Air	Reference Velocity m/sec	Fuel-Air Ratio g fuel/g air — Metered — Main Stage	Metered — Pilot Stage	Metered — Over-All	Sample — Over-All	Sample Combustion Efficiency %	Emission Indices g/kg fuel — CO	HC	NO_x	Engine NO_x	Engine CO	SAE Smoke Number	Total Pressure Loss %	Average Exit Temperature K	Profile Factor	Pattern Factor	Notes
1	100	2.90	438	13.5	0	4.1	17.9	0	0	0	0	--	--	--	--	--	--	--	--	438	--	--	
5	104	2.89	426	14.1	582	[illegible]	18.0	0	0.0115	0.0115	0.0128	95.1	86.8	29.1	[illegible]	2.2	--	10.4	3.56	851	1.05	0.55	1,5
2	101	2.93	435	13.4	472	4.1	17.4	0	0.0098	0.0098	0.0103	93.8	91.8	40.7	1.9	1.7	--	--	3.58	794	1.03	0.32	2
3	102	2.91	430	13.4	587	4.0	17.3	0	0.0122	0.0122	0.0130	95.3	88.9	26.2	2.5	2.3	--	5.9	3.52	881	1.05	0.46	2,5
4	103	2.91	426	14.2	695	4.0	18.1	0	0.0136	0.0136	0.0152	96.5	82.6	15.8	2.4	2.4	--	--	4.37	930	1.05	0.36	2
6	601	3.37	455	16.3	678	4.6	19.1	0	0.0116	0.0116	0.0127	97.0	73.1	13.1	3.2	2.6	--	--	4.03	889	1.05	0.38	2
24	204	3.42	625	14.1	695	4.5	22.7	0	0.0137	0.0137	0.0160	99.1	29.6	2.5	4.4	5.5	5.4	--	4.29	1125	1.11	0.82	1, 6
25	205	3.42	629	14.0	701	4.0	22.8	0.0080	0.0059	0.0139	0.0153	89.0	97.0	87.2	3.2	5.5	74.3	1.6	4.34	1083	1.07	0.78	1,3,5
22	215	[illegible]	628	27.9	1377	5.2	22.7	0.0079	0.0058	0.0137	0.0154	90.7	87.2	73.0	4.0	5.1	77.7	--	4.38	1084	1.14	0.65	1,3
26	206	[illegible]	629	14.0	691	4.0	22.7	0.0099	0.0038	0.0137	0.0134	80.6	106.0	169.6	2.3	4.0	82.8	--	4.16	1035	1.05	1.00	1,3
7	201	3.42	630	14.1	700	3.9	22.6	0	0.0138	0.0138	0.0154	99.3	27.9	0.5	5.3	6.3	4.8	--	4.14	1134	1.07	0.40	2, 6
23	211	6.85	629	27.9	1395	5.8	22.7	0	0.0139	0.0139	0.0156	99.7	11.6	0.4	6.3	6.9	5.4	--	4.24	1138	1.09	0.45	2, 6
28	203	3.42	625	13.9	689	3.9	22.6	0.0080	0.0057	0.0137	0.0135	81.9	111.0	155.0	2.7	4.8	87.2	--	3.98	1038	1.06	0.71	2,3
20	213	6.83	630	27.6	1372	4.9	22.7	0.0080	0.0057	0.0138	0.0151	87.6	[illegible]	100.3	4.0	5.0	90.7	--	4.52	1074	1.09	0.81	2,3
27	202	3.40	626	14.0	698	4.0	22.8	0.0065	0.0074	0.0139	0.0141	88.1	107.0	93.9	4.5	7.9	83.5	--	4.17	1076	1.06	0.83	2,3
21	212	6.87	628	27.8	1381	5.3	22.6	0.0065	0.0073	0.0138	0.0153	90.8	99.7	69.0	6.1	7.7	89.6	--	4.43	1089	1.06	0.57	2,3
10	406	4.75	786	17.2	1294	4.4	24.9	0.0141	0.0068	0.0209	0.0236	98.9	38.0	2.4	10.5	23.1	18.7	--	4.20	1494	1.06	0.26	2,4
9	405	4.76	786	17.6	1303	4.5	25.4	0.0149	0.0057	0.0206	0.0230	98.1	54.2	6.7	7.4	16.7	31.4	--	4.39	1479	1.07	0.28	2,4
8	404	4.76	788	17.4	1304	4.5	25.2	0.0161	0.0047	0.0208	0.0231	97.1	64.9	13.8	5.1	11.2	40.0	--	4.15	1479	1.07	0.31	2,4
16	506	4.80	820	16.4	1364	4.2	24.7	0.0182	0.0049	0.0231	0.0258	98.9	28.9	3.8	8.4	19.4	11.6	--	3.91	1587	[illegible]	0.24	1,4
15	505	4.79	822	16.5	1358	4.3	24.9	0.0190	0.0038	0.0228	0.0257	98.2	38.4	9.2	7.4	17.0	18.1	0.5	3.95	1575	[illegible]	0.30	1,4,5
14	504	4.80	821	16.5	1365	4.0	24.8	0.0199	0.0030	0.0229	0.0255	96.4	53.0	24.0	5.3	[illegible]	29.1	--	3.96	1564	1.05	0.34	1,4
17	514	9.58	813	33.6	2716	3.8	25.5	0.0197	0.0028	0.0225	0.0238	98.1	41.3	9.0	7.3	12.1	28.5	--	4.14	1557	1.08	0.27	1,4
13	503	4.78	821	16.7	1362	4.2	25.1	0.0149	0.0077	0.0226	0.0256	99.7	13.3	0.2	14.0	32.9	2.8	--	4.07	1580	1.07	0.26	2,4
12	502	4.75	821	16.6	1364	4.1	25.1	0.0170	0.0058	0.0228	0.0256	99.6	15.9	0.4	9.8	23.1	4.4	--	4.09	1585	1.07	0.28	2,4
19	512	9.59	818	33.9	2713	4.7	25.8	0.0165	0.0057	0.0222	0.0253	99.7	[illegible]	0.2	12.7	22.3	6.0	--	4.27	1566	1.09	0.26	2,4
11	501	4.72	819	16.4	1362	4.2	25.0	0.0193	0.0038	0.0231	0.0257	98.9	31.7	3.4	4.9	11.5	16.0	1.7	3.95	1586	1.05	0.30	2,4,5
18	511	9.59	818	33.5	2716	3.8	25.5	0.0187	0.0038	0.0225	0.0257	99.3	23.1	1.5	7.0	11.9	15.1	--	4.12	1570	1.09	0.28	2,4

Notes:
1. Alternate Pilot Injectors Fueled
2. All Pilot Injectors Fueled
3. Alternate Pairs of Main Injectors Fueled
4. All Main Injectors Fueled
5. High Density Sampling Mode
6. Engine NO_x Calculated Using 0.2 Power of P_3

Table LVIII. Summary of Test Results, Configuration R2.

Reading Number	Point Number	Inlet Total Pressure Atm	Inlet Total Temperature K	Combustor Airflow kg/sec	Total Fuel Flow kg/hr	Inlet Air Humidity g/kg Air	Reference Velocity m/sec	Fuel-Air Ratio g fuel / g air, Metered, Main Stage	Metered, Pilot Stage	Metered, Overall	Sample, Overall	Sample Combustion Efficiency %	Emission Indices g/kg fuel, CO	HC	NO_x	Engine NO_x	Engine CO	SAE Smoke Number	Total Pressure Loss %	Average Exit Temperature K	Profile Factor	Pattern Factor	Notes
59	100	2.91	429	14.0	0	--	18.3	0	0	0	0	--	--	--	--	--	--	--	4.18	429	--	--	
65	106	2.86	432	[illegible]	704	3.8	16.5	0	0.0161	0.0161	0.0178	98.6	49.0	2.1	3.4	2.9	--	--	3.56	1035	1.09	0.42	
60	104	2.91	430	13.9	689	2.3	18.2	0	0.0138	0.0138	0.0149	98.4	55.1	2.8	2.9	2.6	--	--	4.53	951	1.07	0.45	
64	105	2.88	430	15.3	641	3.6	17.3	0	0.0137	0.0137	0.0155	98.6	49.8	2.9	3.6	3.2	--	--	3.93	949	1.09	0.42	
61	103	2.91	430	13.8	574	1.9	18.2	0	0.0116	0.0116	0.0126	98.2	53.6	5.7	3.3	3.0	--	0.8	4.34	871	1.08	0.64	1
62	102	2.91	430	13.8	473	2.5	18.2	0	0.0095	0.0095	0.0101	97.2	58.6	14.1	3.2	3.0	--	--	4.25	794	1.09	0.42	
63	101	2.91	430	13.9	299	2.6	18.2	0	0.0060	0.0060	0.0062	87.8	129.2	92.1	1.8	1.7	--	--	4.19	641	1.14	0.51	
88	601	3.38	450	16.0	677	6.7	18.2	0	0.0118	0.0118	0.0138	98.8	41.6	2.6	3.6	4.4	--	--	4.38	763	1.14	0.48	
68	200	1.72	625	19.5	0	9.4	20.6	0	0	0	0	--	--	--	--	--	--	--	4.38	625	--	--	
66	201	4.78	639	19.8	996	4.8	23.5	0	0.0140	0.0140	0.0155	99.7	12.5	0.4	8.1	9.1	2.1	0.8	5.01	1148	1.06	0.41	4
67	202	4.74	633	19.7	1004	4.6	23.3	0.0065	0.0077	0.0142	0.0156	93.8	83.4	42.2	5.2	7.8	67.1	--	5.04	1120	[illegible]	0.73	2
69	203	4.80	623	19.9	976	5.5	20.7	0.0080	0.0057	0.0137	0.0153	90.3	91.9	75.2	3.2	4.6	75.2	0.6	4.57	1076	1.11	1.07	1,2
70	204	4.77	630	19.9	979	8.8	20.9	0.0089	0.0048	0.0137	0.0152	86.6	99.8	110.6	2.4	3.5	82.6	--	4.65	1065	1.12	1.20	2
71	205	4.79	629	19.3	984	2.8	20.0	0.0081	0.0060	0.0141	0.0153	88.0	110.7	94.5	2.8	3.6	93.1	1.2	4.20	1085	1.13	1.63	1,3
72	206	4.80	631	19.1	984	7.1	19.8	0.0093	0.0050	0.0143	0.0157	83.4	116.8	138.7	1.9	2.6	98.9	--	4.12	1068	1.16	0.71	3
73	207	4.78	632	19.1	978	[illegible]	20.1	0.0102	0.0040	0.0142	0.0136	74.1	126.6	229.2	1.2	1.8	108.1	--	4.25	1019	1.19	1.05	3
80	301	4.78	730	17.6	1333	5.8	22.8	0	0.0210	0.0210	0.0236	99.8	6.7	0.3	7.5	10.9	6.0	5.3	4.38	1455	1.07	0.32	1
79	302	4.77	725	17.5	1325	5.7	22.7	0.0137	0.0074	0.0211	0.0241	99.0	32.3	2.7	6.7	10.0	21.5	--	4.49	1449	1.07	0.32	2
78	303	4.78	726	17.8	1330	5.6	22.9	0.0149	0.0058	0.0207	0.0244	98.8	35.8	3.9	5.3	7.9	24.6	--	4.52	1437	1.07	0.31	2
77	304	4.79	733	18.0	1332	6.2	23.3	0.0158	0.0048	0.0206	0.0242	98.5	41.2	5.9	4.6	6.8	29.3	--	4.68	1437	1.04	[illegible]	2
76	305	4.74	729	16.7	1342	7.1	23.0	0.0145	0.0078	0.0223	0.0251	99.2	29.2	1.7	8.0	12.2	18.8	--	4.24	1489	1.07	[illegible]	3
75	306	4.73	735	16.7	1329	6.2	23.3	0.0158	0.0063	0.0221	0.0254	98.9	34.4	3.1	5.7	8.4	23.2	--	4.31	1488	1.07	0.32	3
74	307	4.78	728	16.6	1325	7.5	22.8	0.0171	0.0052	0.0223	0.0249	98.5	40.4	5.9	4.9	7.5	28.5	--	4.15	1483	1.07	0.32	3
81	401	4.74	779	17.1	1305	5.5	24.5	0.0139	0.0073	0.0212	0.0244	99.4	21.1	0.8	10.0	23.2	7.4	--	4.69	1499	1.05	0.53	2
82	402	4.76	781	16.9	1303	6.3	24.4	0.0165	0.0049	0.0214	0.0251	99.2	27.3	2.0	6.3	14.5	11.3	--	4.52	1506	1.05	0.56	2
83	403	4.76	781	16.9	1308	6.5	24.4	0.0141	0.0074	0.0215	0.0247	[illegible]	19.0	0.4	9.4	21.8	6.1	--	4.53	1511	1.06	0.66	3
84	404	4.55	783	16.9	1311	6.3	24.4	0.0166	0.0049	0.0215	0.0250	99.3	26.4	1.1	6.2	14.2	10.5	--	4.56	1513	1.07	0.38	3
85	501	4.59	810	16.6	1371	6.2	24.7	0.0161	0.0069	0.0230	0.0262	99.7	10.8	0.2	9.8	25.0	1.7	--	4.46	1583	1.07	0.33	3
86	502	4.60	812	16.7	1366	6.4	24.8	0.0179	0.0048	0.0227	0.0261	99.6	15.4	0.3	7.2	18.1	3.7	--	4.55	1573	1.07	0.34	3
87	503	4.80	811	16.7	1363	6.2	24.9	0.0188	0.0039	0.0227	0.0258	99.4	23.3	0.9	6.4	16.4	8.9	--	4.55	1572	1.07	0.33	3

Note:
1. High Density Sampling Mode
2. Alternate Main Injectors Fueled
3. All Main Injectors Fueled
4. Engine NO_x Calculated Using 0.2 Power of P_3

Table LIX. Summary of Test Results, Configuration R3.

Reading Number	Point Number	Inlet Total Pressure Atm.	Inlet Total Temperature K	Combustor Airflow kg/sec	Total Fuel Flow kg/hr	Inlet Air Humidity g/kg Air	Reference Velocity m/sec	Fuel-Air Ratio g fuel/g air: Metered Main Stage	Metered Pilot Stage	Metered Over-All	Sample Over-All	Sample Combustion Efficiency %	Emission Indices g/kg fuel: CO	HC	NO_x	Engine NO_x	Engine CO	SAE Smoke Number	Total Pressure Loss %	Average Exit Temperature K	Profile Pattern	Profile Factor	Notes
126	100	2.88	429	13.7	0	--	18.2	0	0	0	0	--	--	--	--	--	--	--	--	429	--	--	--
142	100	2.87	421	14.0	0	--	18.2	0	0	0	0	--	--	--	--	--	--	--	3.62	421	--	--	--
128	101	2.90	433	13.5	402	4.6	18.0	0	0.0083	0.0083	0.0090	94.7	75.6	35.5	2.7	2.5	--	--	--	744	1.18	0.65	--
129	102	2.89	430	13.5	583	4.3	17.9	0	0.0120	0.0120	0.0138	98.1	51.9	6.7	3.3	3.1	--	0.8	--	888	1.17	0.58	1
130	103	2.90	434	12.9	638	4.9	17.4	0	0.0137	0.0137	0.0161	98.5	47.9	3.4	3.2	3.1	--	--	--	952	1.15	0.51	6% Bld
131	104	2.85	433	12.2	699	4.3	16.7	0	0.0159	0.0159	0.0184	98.6	46.8	2.7	3.1	3.0	--	--	--	1029	1.13	0.57	12% Bld
132	105	3.56	460	16.7	679	4.3	19.2	0	0.0113	0.0113	0.0131	98.7	41.0	3.8	4.0	3.8	--	--	4.17	890	1.19	0.73	4.8% F_N
133	106	4.54	488	20.8	825	3.9	18.2	0	0.0110	0.0110	0.0129	99.3	26.3	1.3	4.9	4.4	--	5.5	4.13	909	1.20	0.56	7.0% F_X
134	201	3.38	631	13.8	348	4.0	22.9	0	0.0070	0.0070	0.0079	99.4	19.8	1.1	7.9	9.5	1.9	--	4.16	896	1.17	0.67	3
152	211	6.80	631	27.5	698	2.1	22.7	0	0.0070	0.0070	0.0080	99.7	9.1	1.4	11.5	11.3	3.2	--	3.82	899	1.18	0.55	3
135	202	3.39	628	13.7	699	3.7	22.6	0	0.0141	0.0141	0.0163	99.6	16.2	0.2	6.2	7.5	1.4	2.2	4.21	1144	1.21	0.51	3
153	212	6.80	633	27.7	1406	2.1	22.9	0	0.0141	0.0141	0.0172	99.8	7.1	0.3	8.0	8.0	2.5	1.6	3.94	1149	1.23	0.70	3
136	203	3.38	629	13.9	1056	3.3	22.8	0	0.0212	0.0212	0.0248	99.5	20.1	0.1	5.1	6.2	2.0	--	--	1375	1.21	0.62	3
137	401	4.74	786	16.8	1284	2.8	24.9	0.0173	0.0039	0.0212	0.0232	92.2	73.0	60.7	3.8	8.1	46.6	--	3.86	1454	1.07	0.41	--
149	411	9.53	783	33.9	2591	2.2	25.0	0.0173	0.0039	0.0212	0.0242	95.7	65.8	27.3	5.6	8.6	49.5	--	3.83	1476	1.07	0.38	--
138	402	4.72	785	16.8	1287	3.3	25.0	0.0165	0.0048	0.0213	0.0239	96.7	56.4	19.9	5.3	11.9	33.3	--	3.81	1488	1.06	0.32	--
150	412	9.53	783	34.2	2591	2.7	25.0	0.0163	0.0048	0.0211	0.0245	98.2	46.6	7.6	7.8	12.0	32.5	--	3.84	1490	1.08	0.33	--
139	403	4.68	775	16.7	1296	3.5	24.7	0.0145	0.0070	0.0215	0.0242	98.9	33.1	3.7	9.0	20.7	15.3	2.6	3.85	1502	1.06	0.27	1
151	413	9.53	780	34.1	2577	2.4	24.9	0.0142	0.0068	0.0210	0.0244	99.1	29.9	1.7	12.6	19.6	18.1	0.9	3.89	1494	1.06	0.28	--
141	404	4.74	773	16.9	1283	3.6	24.6	0.0172	0.0039	0.0211	0.0231	97.4	51.6	14.3	6.5	15.1	29.5	--	3.84	1478	1.06	0.43	2
140	405	4.76	778	17.1	1290	3.5	24.9	0.0141	0.0068	0.0209	0.0237	99.1	30.4	2.4	11.2	25.6	13.5	2.3	3.77	1489	1.06	0.57	1, 2
143	501	4.74	821	16.4	1363	1.8	25.5	0.0189	0.0039	0.0228	0.0262	97.8	43.7	12.1	5.8	13.3	21.9	--	3.83	1569	1.07	0.40	--
146	511	9.53	809	32.8	2729	0.7	25.0	0.0191	0.0040	0.0231	0.0268	98.9	27.2	1.6	7.2	11.9	15.0	--	3.80	1578	1.07	0.30	--
144	502	4.74	820	16.4	1360	1.4	25.3	0.0181	0.0050	0.0231	0.0260	99.1	28.1	2.4	7.5	17.0	11.0	--	3.75	1588	1.07	0.32	--
147	512	9.53	819	32.5	2717	1.8	25.1	0.0182	0.0050	0.0232	0.0269	99.6	14.5	1.0	8.9	14.2	6.1	--	3.71	1595	1.07	0.30	--
145	503	4.74	815	16.5	1362	1.7	25.3	0.0161	0.0069	0.0230	0.0264	99.6	16.0	0.5	10.3	24.2	4.0	2.0	3.71	1585	1.06	0.28	--
148	504	9.53	818	32.7	2726	1.9	25.1	0.0162	0.0070	0.0232	0.0272	99.8	8.1	0.5	14.3	23.1	2.1	0.5	3.68	1595	1.07	0.27	--

Notes: 1. High Density Sampling Mode
2. Alternate Main Injectors Fueled
3. Engine NO_x Calculated Using 0.2 Power of P_3

Table LX. Summary of Test Results, Configuration R4.

Reading Number	Point Number	Inlet Total Pressure Atm	Inlet Total Temperature K	Combustor Airflow kg/sec	Total Fuel Flow kg/hr	Inlet Air Humidity g/kg Air	Reference Velocity m/sec	Fuel-Air Ratio g fuel/g air: Metered Main Stage	Metered Pilot Stage	Metered Over-All	Sample Over-All	Sample Combustion Efficiency %	Emission Indices g/kg fuel: CO	HC	NO_x	Eng NO_x	Eng CO	SAE Smoke Number	Total Pressure Loss %	Average Exit Temperature K	Profile Factor	Pattern Factor	Notes
185	100	2.89	429	14.0	0	3.8	18.5	0	0	0	0	--	--	--	--	--	--	--	3.99	430	--	--	
189	104	2.91	430	13.8	663	2.7	18.2	0	0.0133	0.0133	0.0149	98.8	48.7	0.8	2.9	2.7	--	--	4.09	936	1.13	0.57	
188	103	2.89	430	13.8	574	2.9	18.3	0	0.0115	0.0115	0.0130	98.8	44.8	1.3	3.2	3.0	--	0	4.23	873	1.13	0.60	1
190	105	2.92	429	13.8	465	2.9	18.2	0	0.0093	0.0093	0.0107	98.9	37.5	1.8	3.8	3.6	--	--	4.11	793	1.16	0.69	
187	102	2.91	429	13.8	396	3.6	18.2	0	0.0080	0.0080	0.0085	98.5	37.5	6.5	3.8	3.6	--	--	4.19	740	1.13	0.41	
186	101	2.91	429	13.8	249	3.6	18.2	0	0.0050	0.0050	0.0047	60.3	145.3	363.6	0.3	0.3	--	--	3.60	551	1.17	0.89	
193	203	3.42	629	14.2	646	4.3	23.2	0	0.0127	0.0127	0.0140	99.6	17.5	0.1	6.2	7.6	1.5	1	4.08	1095	1.21	0.67	1,2
192	202	3.43	629	14.1	499	2.7	23.0	0	0.0099	0.0099	0.0109	99.6	15.8	0.2	8.4	10.1	1.3	--	4.08	997	1.20	0.70	2
191	201	3.37	629	13.9	343	2.9	23.2	0	0.0068	0.0068	0.0073	99.6	12.4	0.8	7.8	9.4	1.1	--	4.03	889	1.22	0.86	2
194	301	4.78	733	17.7	1320	2.7	24.3	0.0130	0.0077	0.0207	0.0224	96.5	79.6	16.6	7.1	10.2	64.9	--	3.99	1424	1.07	0.25	
195	302	4.78	731	17.6	1324	4.2	24.2	0.0139	0.0069	0.0208	0.0222	94.8	87.8	31.4	5.5	8.2	72.5	--	4.03	1416	1.08	0.27	
196	303	4.75	733	17.7	1322	3.8	24.5	0.0158	0.0049	0.0207	0.0218	89.0	79.6	86.9	2.8	4.2	82.9	--	4.06	1373	1.08	0.36	
200	404	4.75	784	17.0	1313	4.2	25.2	0.0118	0.0097	0.0215	0.0231	98.3	51.1	5.4	10.1	22.6	30.4	--	3.97	1505	1.07	0.31	
199	403	4.77	785	17.0	1308	3.8	25.0	0.0146	[illegible]	0.0214	0.0234	97.8	56.7	8.3	7.1	15.7	35.0	--	3.97	1500	1.07	0.25	
198	402	4.76	784	17.0	1313	4.2	25.1	0.0167	0.0048	0.0215	0.0237	95.4	72.4	29.5	3.6	8.1	48.2	1	3.96	1483	1.06	0.34	1
201	405	4.75	785	17.0	1538	4.3	25.1	0.0202	0.0049	0.0251	0.0277	98.5	37.0	6.6	4.6	10.4	19.3	--	4.17	1614	1.07	0.28	
197	401	4.76	785	16.8	1311	4.0	24.9	0.0179	0.0038	0.0217	0.0234	89.7	84.8	83.5	2.3	5.0	58.8	--	3.93	1448	1.06	0.36	
204	503	4.76	820	16.6	1364	4.1	25.6	0.0160	0.0069	0.0229	0.0250	99.3	23.5	1.6	9.0	21.7	8.6	--	3.94	1583	1.07	0.27	
203	502	4.77	820	16.5	1368	4.2	25.5	0.0180	0.0050	0.0230	0.0254	98.5	37.7	6.5	5.1	12.3	18.3	0	3.89	1581	1.06	0.30	1
202	501	4.76	817	16.5	1366	4.3	25.5	0.0190	0.0040	0.0230	0.0255	95.7	58.1	29.8	3.4	8.3	34.0	--	3.96	1556	1.06	0.32	

Notes:

1. High Density Sampling Mode
2. Engine NO_x Calculated Using 0.2 Power of P_3

Table LXI. Summary of Test Results, Configuration R5.

Reading Number	Point Number	Inlet Total Pressure Atm	Inlet Total Temperature K	Combustor Airflow kg/sec	Total Fuel Flow kg/hr	Inlet Air Humidity g/kg Air	Reference Velocity m/sec	Fuel-Air Ratio g fuel/g air, Metered, Main Stage	Metered, Pilot Stage	Metered, Overall	Sample, Overall	Sample Combustion Efficiency %	Emission Indices g/kg fuel, CO	HC	NO_x	Engine NO_x	Engine CO	SAE Smoke Number	Total Pressure Loss %	Average Exit Temperature K	Profile Factor	Pattern Factor	Notes
205	100	2.92	430	13.9	0	---	18.2	0	0	0	0	---	---	---	---	---	---	---	4.61	430	---	---	
209	100	2.97	434	14.1	0	---	18.3	0	0	0	0	---	---	---	---	---	---	---	4.80	434	---	---	
226	100	2.85	431	13.5	0	---	18.1	0	0	0	0	---	---	---	---	---	---	---	4.21	431	---	---	
212	104	2.91	431	13.7	672	1.1	18.2	0	0.0136	0.0136	0.0157	98.9	46.3	0.5	3.2	2.8	---	---	5.73	948	1.08	0.33	
210	103	2.89	432	13.6	589	1.0	18.0	0	0.0121	0.0121	0.0136	98.8	43.8	1.5	3.4	3.0	---	1	5.58	895	1.09	0.32	1
211	106	2.90	431	13.7	518	1.1	18.2	0	0.0105	0.0105	0.0112	98.8	40.4	2.2	3.4	3.0	---	---	5.39	838	1.05	0.26	
207	102	2.93	429	13.8	444	0.6	18.0	0	0.0090	0.0090	0.0092	98.5	39.9	5.8	2.8	2.5	---	---	4.81	778	1.07	0.29	
206	101	2.91	429	13.7	345	0.6	18.0	0	0.0070	0.0070	0.0071	94.3	86.4	36.8	1.5	1.3	---	---	4.72	692	1.14	0.42	
215	203	3.41	630	13.6	668	1.0	22.4	0	0.0137	0.0137	0.0150	99.6	15.1	0.1	7.2	8.5	1.3	---	5.02	1130	1.10	0.31	1, 2
214	202	3.40	627	13.7	493	1.2	22.5	0	0.0100	0.0100	0.0107	99.7	10.3	0.2	8.6	10.3	0.9	---	5.15	1000	1.11	0.35	2
213	201	3.38	630	13.7	351	1.1	22.8	0	0.0071	0.0071	0.0075	99.8	9.1	0.4	5.5	6.2	0.8	---	5.12	900	1.13	0.41	2
216	301	4.76	731	17.5	1309	1.1	24.0	0.0125	0.0083	0.0208	0.0239	98.2	53.0	5.2	5.7	8.0	40.3	---	4.94	1440	1.08	0.24	
217	302	4.78	732	17.4	1301	1.1	24.0	0.0139	0.0069	0.0208	0.0238	97.6	60.3	10.3	4.4	6.1	47.0	---	4.88	1434	1.08	0.25	
218	303	4.74	734	17.5	1307	1.1	24.3	0.0162	0.0045	0.0207	0.0233	90.7	88.0	72.4	2.2	3.1	72.6	---	5.03	1385	1.07	0.31	
223	405	4.76	783	17.1	1285	1.1	25.1	0.0141	0.0168	0.0209	0.0237	98.6	41.0	4.2	5.4	11.4	21.8	---	4.83	1489	1.07	0.24	
220	402	4.78	785	16.8	1288	1.1	24.7	0.0163	0.0050	0.0213	0.0246	96.9	54.2	18.2	3.0	6.3	32.3	5	4.87	1488	1.07	0.29	1
221	403	4.79	784	17.0	1388	1.0	24.9	0.0179	0.0049	0.0228	0.0261	98.2	39.9	9.2	3.4	7.2	21.0	---	4.89	1542	1.07	0.30	
222	404	4.80	780	17.0	1503	1.0	24.8	0.0196	0.0049	0.0245	0.0280	99.1	23.9	3.5	4.1	8.8	9.5	---	4.83	1599	1.07	0.25	
219	401	4.70	783	16.6	1283	1.0	24.9	0.0174	0.0040	0.0214	0.0236	89.8	78.3	83.7	2.1	4.5	52.2	---	4.90	1439	1.08	0.33	
225	502	4.73	819	16.4	1355	0.7	25.4	0.0180	0.0050	0.0230	0.0270	97.8	36.7	13.6	4.4	10.0	17.5	---	4.72	1574	1.05	0.17	1
224	501	4.71	818	16.4	1346	0.7	25.5	0.0187	0.0040	0.0227	0.0259	97.7	44.3	12.9	3.3	7.9	23.1	---	4.73	1566	1.07	0.24	

Notes:

1. High Density Sampling Mode
2. Engine NO_x Calculated Using 0.2 Power of P_3

Table LXII. Summary of Test Results, Configuration R6.

Reading Number	Point Number	Inlet Total Pressure Atm	Inlet Total Temperature K	Combustor Airflow kg/sec	Total Fuel Flow kg/hr	Inlet Air Humidity g/kg Air	Reference Velocity m/sec	Fuel-Air Ratio g fuel/ g air — Metered: Main Stage	Metered: Pilot Stage	Metered: Over-All	Sample: Over-All	Sample Combustion Efficiency %	Emission Indices g/kg fuel: CO	HC	NO_x	Eng NO_x	Eng CO	SAE Smoke Number	Total Pressure Loss %	Average Exit Temperature K	Profile Factor	Pattern Factor	Notes
257	100	2.95	429	13.8	--	2.4	17.9	--	--	--	--	--	--	--	--	--	--	--	3.37	429	--	--	
273	100	2.91	429	13.9	--	0.8	18.2	--	--	--	--	--	--	--	--	--	--	--	3.81	429	--	--	
261	104	2.97	429	13.9	673	2.4	17.9	0	0.0134	0.0134	0.0157	99.3	29.9	0.2	3.1	2.8	--	--	4.28	943	1.06	0.34	
260	103	2.96	431	14.0	585	2.5	18.1	0	0.0116	0.0116	0.0134	99.4	23.9	0.3	3.1	2.8	--	2	4.31	878	1.06	0.36	1
262	105	2.96	430	13.9	496	2.5	18.1	0	0.0099	0.0099	0.0112	99.4	23.2	1.1	3.2	2.9	--	--	4.32	816	1.07	0.33	
259	102	2.99	430	13.9	445	2.3	17.8	0	0.0089	0.0089	0.0098	99.3	22.8	2.1	2.7	2.4	--	--	4.13	780	1.06	0.30	
258	101	2.95	430	13.9	337	2.6	18.1	0	0.0067	0.0067	0.0069	95.6	81.8	25.2	1.6	1.4	--	--	3.82	688	1.06	0.29	
263	203	3.48	622	14.1	668	2.3	22.4	0	0.0132	0.0132	0.0145	99.7	10.8	0.1	7.8	9.3	1.0	1	4.21	1108	1.05	0.28	1,2
264	202	3.48	628	14.2	494	2.3	22.7	0	0.0097	0.0097	0.0106	99.9	4.8	0.1	7.6	8.9	0.4	--	4.19	991	1.06	0.27	2
265	201	3.48	628	14.2	353	2.3	22.6	0	0.0069	0.0069	0.0072	99.9	5.4	0.2	5.3	6.2	0.5	--	4.15	891	1.07	0.29	2
267	205	3.60	628	14.1	703	2.2	21.9	0.0069	0.0070	0.0139	0.0142	76.4	138.3	203.4	1.8	2.9	112.5	--	3.92	1017	1.06	0.41	
266	204	3.50	628	14.2	699	2.3	22.6	0.0089	0.0048	0.0137	0.0102	60.1	104.7	374.6	0.8	1.3	81.3	--	4.01	930	1.05	0.83	
268	301	4.92	729	17.9	1339	2.5	23.7	0.0129	0.0079	0.0208	0.0238	98.9	38.7	2.4	5.9	8.4	27.4	--	4.21	1441	1.05	0.23	
269	302	4.77	729	17.4	1334	2.4	23.9	0.0141	0.0072	0.0213	0.0242	98.9	39.2	2.2	5.5	7.9	27.6	--	4.21	1458	1.05	0.24	
270	303	4.77	729	17.6	1336	2.3	24.0	0.0160	0.0050	0.0210	0.0238	95.3	73.4	30.0	3.5	5.1	58.5	--	4.33	1423	1.06	0.35	
271	404	4.77	780	17.1	1324	3.9	25.1	0.0143	0.0071	0.0214	0.0243	99.2	20.0	3.0	6.0	13.6	6.7	--	4.39	1507	1.05	0.30	

Notes:

1. High Density Sampling Mode
2. Engine NO_x Calculated Using 0.2 Power of P_3

Table LXIII. Summary of Pattern and Profile Factors For Atmospheric Pressure Combustor Test, Configuration R7.

Point Number	Inner Total Pressure atm	Inlet Total Temperature K	Combustor Airflow kg/s	Fuel-Air Ratio g Fuel/g Air			Pattern Factor	Profile Factor
				Pilot	Main	Total		
10	1.05	426	191	0	.0109	.0109	.42	1.07
20	1.05	629	207	0	.0136	.0136	.48	1.05
30	1.05	756	281	.0160	.0050	.0210	.86	1.08
31	1.05	756	303	.0189	.0038	.0227	1.24	1.12
32	1.05	755	305	.0179	.0049	.0228	.72	1.11
33	1.05	754	310	.0171	.0060	.0231	.36	1.10
40	1.05	808	299	.0175	.0054	.0229	.34	1.11

Table LXIV. Summary of Sea Level Ignition Test Results, Configuration R7.

Point Number	Inlet Total Pressure Atm	Inlet Total Temperature K	Combustor Airflow kg/s	Type Ignitor	Required Fuel Flow (kg/hr)				
					Lightoff	50% Propagation	100% Propagation	50% Cups Out	Lean Blowout
50	.99	299	2.67	spark	266	266	266	152	82
					219	225	246	157	87
					223	244	247	148	92
					227	255	255		
60	1.01	300	3.64	spark	233	246	261	214	147
					266	266	266	190	140
					266	271	289	205	130
					261	271	278	-	-
60	1.01	300	3.64	torch	227	-	-	197	138
70	1.03	304	5.35	spark	266	290	317	290	227
					264	308	323	285	234
					280	299	329	289	230

Notes:

a. JP-5 at 295 K

b. Barometric pressure = .982 atmospheres

Table LXV. Summary of Sea Level Efficiency Test Results, Configuration R7.

Point Number	Inlet Total Pressure atm	Inlet Total Temperature K	Combustor Airflow kg/s	Metered Fuel-Air Ratio g Fuel/g Air	Measured Temperature Rise K	Combustor Efficiency %
52	1.00	299	2.67	.0234	604	67.2
53	1.00	298	2.66	.0282	848	81.2
61	1.01	299	3.63	.0207	612	76.0
62	1.02	299	3.62	.0241	783	85.0
63	1.02	299	3.58	.0281	892	85.4
71	1.05	302	5.40	.0184	584	80.8
72	1.05	302	5.40	.0206	688	86.0
73	1.06	301	5.44	.0224	768	89.2

Notes:

a. JP-5 at 295 K

b. Barometric Pressure = 0.982 atmospheres

Table LXVI. Summary of Test Results, Configuration R7.

Reading Number	Point Number	Inlet Total Pressure Atm	Inlet Total Temperature K	Combustor Airflow kg/sec	Total Fuel Flow kg/hr	Inlet Air Humidity g/kg Air	Reference Velocity m/sec	Fuel-Air Ratio g Fuel/g Air: Metered			Fuel-Air Ratio g Fuel/g Air	Sample Combustion Efficiency %	Emission Indices g/kg Fuel					SAE Smoke Number	Total Pressure Loss %	Average Exit Temperature K	Profile Factor	Pattern Factor	Notes
								Main Stage	Pilot Stage	Overall	Sample Overall		CO	HC	NO_x	Engine NO_x	Engine CO						
375	100	2.93	433	13.7	0	---	18.1	0	0	0	0	---	---	---	---	---	---	---	4.89	433	---	---	
376	101	2.95	431	13.7	693	4.30	18.0	0	.0140	.0140	.0159	98.8	37.1	3.4	2.8	2.6	---	0.5	5.49	963	1.06	0.58	
377	102	2.92	433	13.7	575	4.08	18.2	0	.0116	.0116	.0128	98.1	48.8	7.9	2.8	2.6	---	0.3	5.47	876	1.06	0.62	1
378	103	2.94	429	13.7	495	4.08	17.8	0	.0100	.0100	.0107	97.5	56.3	12.1	2.7	2.4	---	0.3	5.23	820	1.08	0.58	
379	104	2.93	434	13.7	396	4.27	17.8	0	.0080	.0080	.0079	91.2	123.0	59.2	1.7	1.6	---	0.3	5.21	729	1.09	0.50	
392	201	3.40	625	13.9	691	4.14	22.6	0	.0138	.0138	.0152	99.8	9.0	0.2	5.2	6.4	0.8	---	5.71	1131	1.07	0.38	2
393	202	3.38	624	13.8	489	3.94	22.7	0	.0098	.0098	.0104	99.7	9.5	0.5	4.8	6.0	0.8	---	5.72	991	1.09	0.40	2
394	301	4.74	733	17.5	1317	4.87	24.2	.0131	.0078	.0209	.0238	95.2	72.6	30.7	2.9	4.4	58.3	---	5.54	1423	1.07	0.43	
395	302	4.74	727	17.9	1324	4.94	24.4	.0158	.0048	.0206	.0196	82.1	77.1	161	1.8	2.8	62.5	---	5.54	1314	1.09	0.91	
396	401	4.72	778	16.4	1307	4.65	24.2	.0183	.0039	.0222	.0182	79.7	65.5	187	0.7	1.6	41.4	0.9	5.80	1381	1.11	0.66	
397	402	4.72	778	16.6	1305	4.54	24.6	.0168	.0050	.0218	.0230	88.2	85.8	98.4	1.3	3.0	59.2	2.9	5.32	1433	1.08	0.69	1
398	403	4.74	783	16.7	1305	4.55	24.8	.0147	.0070	.0217	.0247	97.7	47.9	11.9	3.2	7.2	27.4	1.1	5.44	1505	1.06	0.45	
400	501	4.74	813	16.4	1385	4.05	25.2	.0177	.0058	.0235	.0270	98.8	30.3	4.7	3.9	9.7	13.0	0.8	5.40	1592	1.06	0.45	
399	502	4.76	813	16.3	1373	4.28	25.0	.0185	.0048	.0233	.0263	95.3	60.2	33.3	2.8	6.8	35.4	1.1	5.40	1560	1.07	0.53	1
401	512	9.55	818	32.7	2732	5.29	25.2	.0183	.0049	.0232	.0268	97.2	41.8	18.6	4.4	7.6	27.4	0.9	5.08	1575	1.07	0.42	1
402	513	9.53	817	32.7	2369	5.40	25.3	.0152	.0049	.0201	.0229	93.2	76.8	48.7	3.3	6.0	58.6	0.3	5.01	1451	1.08	0.51	
403	514	9.53	817	32.7	2006	5.51	25.2	.0122	.0048	.0170	.0182	86.6	125	105	2.4	4.3	103	0.3	4.87	1319	1.09	0.67	
404	515	9.46	819	33.0	1655	5.48	25.5	.0091	.0048	.0139	.0128	75.4	191	201	2.2	4.1	165	0.9	4.97	1180	1.09	1.14	

NOTES:
1. High Density Sampling Mode
2. Engine NO_x Calculated Using 0.2 Power of P_3

APPENDIX D

SECTOR RIG TEST DATA

This appendix contains summaries of the operating conditions, combustor performance data, and exhaust emission data for each sector rig test conducted in the Phase II Program. The sequence in which these tests were conducted is presented in Table LXVII. The detailed data summaries are then presented in Tables LXVIII through XCV.

Table LXVII. Sector Combustor Test Sequence.

60° Sector Rig Run Number	Test Date	Configuration Number	Type Test (1)	Data Table Number
1	10/16/74	S1	2	LXVIII & Ref 9
2	10/24/74	S1	3	LXVIII
3	10/31/74	S1	3	LXVIII
4	11/13/74	DS1A	2	LXIX
5	11/25/74	DS1B	2	LXIX
6	12/5/74	RS1A	2	LXXXIX
7	12/19/74	DS2A	2	LXX
8	12/20/74	DS2B	2	LXX
9	12/23/74	DS2C	2	LXX
10	12/31/74	DS2C	3	LXX
11	1/7/75	DS2D	2	LXX
12	1/14/75	RS1B	2	LXXXIX
13	1/24/75	DS3	2	LXXI
14	1/28/75	DS4	2	LXXII
15	2/18/75	DS4	4	LXXXIII
16	2/26/75	DS3	4	LXXXIII
17	2/27/75	DS5A	4	LXXXIII
18	3/3/75	DS5B	4	LXXXIII
19	3/5/75	DS6	4	LXXXIII
20	3/7/75	DS7	4	LXXXIII
21	3/11/75	RS2A	2	XC
22	3/12/75	RS2B	2	XC
23	3/14/75	DS5B	2	LXXIII
24	3/18/75	DS5B	3	LXXIII
25	3/26/75	DS5A	2	LXXIII
26	4/8/75	DS5C	3	LXXIII
27	4/21/75	S1	2	Ref 9
28	4/22/75	S1	2	Ref 9
29	4/22/75	S1	2	Ref 9
30	4/24/75	DS8	6	LXXXVII
31	4/25/75	DS9	6	LXXXVII
32	4/26/75	DS10	6	LXXXVII
33	4/28/75	DS11	6	LXXXVII
34	4/28/75	DS12	6	LXXXVII
35	4/29/75	DS13	6	LXXXVII
36	4/30/75	DS14	6	LXXXVII
37	4/30/75	DS15	6	LXXXVII
38	5/3/75	DS16	6	LXXXVII
39	5/3/75	DS17	6	LXXXVII
40	5/4/75	DS18	6	LXXXVII
41	5/12/75	DS19	2	LXXIV
42	5/13/75	DS20	2	LXXIV & Ref 9
43	5/14/75	DS20	2	Ref 9

Table LXVII. Sector Combustor Test Sequence. (Continued)

60° Sector Rig Run Number	Test Date	Configuration Number	Type Test (1)	Data Table Number
44	5/14/75	DS20	2	Ref 9
45	5/15/75	DS20	2	Ref 9
46	5/21/75	RS3	2	Ref 9
47	5/23/75	RS3	2	Ref 9
48	5/27/75	RS3	2	Ref 9
49	5/27/75	RS3	2	XCI & Ref 9
50	5/28/75	DS21	2	LXXVI
51	5/29/75	DS22	2	LXXVII
52	5/30/75	DS23	2	LXXVIII
53	5/30/75	DS24	2	LXXIX
54	6/6/75	DS22	6	LXXXVIII
55	6/10/75	DS25	6	LXXXVIII
56	6/11/75	DS26	6	LXXXVIII
57	6/16/75	DS27	6	LXXXVIII
58	6/20/75	DS28	2	LXXX
59	7/2/75	DS29	2	LXXXI
60	7/21/75	DS30	2	LXXXII
61	7/25/75	DS30	2	Ref 9
62	7/29/75	DS30	2	LXXXII & Ref 9
63	7/29/75	DS30	2	Ref 9
64	7/30/75	DS30	2	Ref 9
65	9/8/75	DS30	3	LXXXII
66	9/17/75	DS31A	4	LXXXIV
67	9/18/75	DS31B	4	LXXXIV
68	9/23/75	DS31C	4	LXXXIV & LXXXV
69	9/24/75	DS31D	4	LXXXIV
70	9/25/75	DS32A	4	LXXXIV
71	9/25/75	DS32B	4	LXXXIV & LXXXV
72	10/6/75	DS33A	4	LXXXIV & LXXXV
73	10/7/75	DS33B	4	LXXXIV
74	10/8/75	DS33C	4	LXXXIV
75	10/9/75	DS33D	4	LXXXIV
76	10/10/75	DS33E	4	LXXXIV
77	10/21/75	DS34	4	LXXXV
78	10/23/75	DS34	5	LXXXVI
79	10/24/75	DS34	5	LXXXVI
80	10/29/75	DS35	5	LXXXVI
81	10/30/75	DS36	5	LXXXVI
82	11/5/75	DS36	4	LXXXV
83	11/7/75	DS35	4	LXXXV
84	11/11/75	DS37	4	LXXXV

Table LXVII. Sector Combustor Test Sequence. (Concluded)

12° Sector Rig Run Number	Test Date	Configuration Number	Type Test (1)	Data Table Number
1	1/30/75	FS1	8	XCIII
2	3/12/75	CS2	7	XCII
3	3/13/75	CS2	7	XCII
4	3/31/75	CS2	7	XCII
5	4/3/75	FS2	8	XCIV
6	4/15/75	CS3	7	XCII
7	4/29/75	CS4	7	XCII
8	5/5/75	CS5	7	XCII
9	5/8/75	CS6	7	XCII
10	5/15/75	CS6	7	XCII & Ref 9
11	5/16/75	FS3	8	XCV & Ref 9
12	6/12/75	CS7	7	XCII
13	6/16/75	CS8	7	XCII
14	8/6/75	CS9	7	XCII & Ref 9

(1) Type Test

- (2) Altitude Relight Ambient Air and Fuel
- (3) Altitude Relight Cold Air and/or Cold Fuel
- (4) Idle Emissions
- (5) Subidle Efficiency (exit temperatures)
- (6) Atmospheric Discharge Cross-fire
- (7) Carboning
- (8) Flashback

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Table LXVIII. Altitude Relight Test Results, Configuration S1.

Combustor Type - Std. Prod. CF6-50 Fuel Injector - Std. Production Nozzles

Alternate Nozzles Fueled

Rdg No.	Simulated Flight Condition Alt. km	Simulated Flight Condition M_p	Combustor Operating Condition T_F K	T_3 K	P_3 atm	W_c kg/s	$\Delta P/P$ %	PT/V atm-K/m/s	Lightoff Attempt W_f (EQUIV) kg/hr	f	Light Off	Blowout Condition (1) W_f (EQUIV) kg/hr	f	Notes
10	3.2	0.29	306	301	0.68	1.33	–	45.4	249	0.0520	Yes	29	0.0061	
1	6.1	0.35	310	307	0.47	1.36	1.06	21.9	249	0.0509	Yes	29	0.0059	
2	7.7	0.38	311	305	0.38	1.53	2.04	12.7	249	0.0452	Yes	37	0.0067	
35	7.8	0.38	311	311	0.38	1.53	–	12.7	249	0.0452	Yes	–	–	
3	8.4	0.48	311	307	0.37	1.99	3.78	9.3	249	0.0348	Yes	64	0.0089	
9	3.7	0.39	307	302	0.66	2.29	1.43	25.3	249	0.0302	Yes	50	0.0061	
8	6.0	0.46	311	302	0.52	2.29	2.34	15.6	249	0.0302	Yes	59	0.0072	
7	6.9	0.49	311	305	0.47	2.30	1.43	12.9	249	0.0300	Yes	48	0.0058	
6	8.7	0.55	311	307	0.39	2.30	2.34	8.9	249	0.0300	Yes	50	0.0060	
11	4.6	0.49	306	301	0.64	3.15	2.83	17.3	249	0.0220	Yes	42	0.0037	
12	7.3	0.61	306	301	0.50	3.15	4.83	10.5	249	0.0220	Yes	48	0.0042	
13	8.2	0.65	311	317	0.46	3.22	5.67	8.7	249	0.0215	Yes	48	0.0041	
31	8.3	0.65	313	312	0.46	3.17	5.93	8.7	249	0.0218	Yes	–	–	
14	8.9	0.68	313	317	0.44	3.22	6.27	7.8	249	0.0215	Yes	37	0.0032	
33	9.1	0.68	312	312	0.43	3.17	6.74	7.7	249	0.0218	Yes	–	–	
28	6.6	0.67	313	312	0.58	4.16	5.90	10.7	249	0.0166	Yes	55	0.0037	
30	10.5	0.90	313	312	0.53	4.16	7.31	8.8	249	0.0166	Yes	–	–	
20	9.3	0.81	311	317	0.50	4.24	8.16	7.7	249	0.0163	Yes	–	–	
22	7.7	0.84	312	317	0.70	5.41	6.48	11.9	249	0.0128	Yes	68	0.0035	
24	10.7	1.02	313	314	0.62	5.38	8.46	9.3	249	0.0129	Yes	66	0.0034	
26	>10.7	>1.00	312	313	0.59	5.35	9.17	8.6	249	0.0129	Yes	–	–	
36	8.7	0.42	313	311	0.34	1.53	–	9.6	249	0.0452	No	–	–	
5	9.1	0.57	311	307	0.37	2.30	5.05	8.0	302	0.0300	No	–	–	
34	9.4	0.58	312	311	0.36	2.31	4.84	7.3	249	0.0300	No	–	–	
18	9.8	0.73	313	319	0.36	4.24	16.4	4.0	249	0.0163	No	–	–	
8	3.2	0.29	307	274	0.68	1.35	–	44.9	249	0.0512	Yes	–	–	
1	6.1	0.35	306	263	0.47	1.38	–	21.5	249	0.0501	Yes	31	0.0062	
2	7.9	0.42	306	251	0.39	1.55	–	12.8	249	0.0446	Yes	27	0.0049	
3	8.7	0.51	306	252	0.37	2.01	–	9.1	249	0.0344	Yes	–	–	
5	6.9	0.49	306	260	0.48	2.33	–	12.8	249	0.0297	Yes	48	0.0057	
11	7.2	0.60	306	267	0.51	3.19	–	10.7	249	0.0217	Yes	46	0.0039	
12	9.0	0.68	306	262	0.43	3.19	–	7.6	249	0.0217	Yes	42	0.0036	
14	8.2	0.74	307	279	0.54	4.19	–	9.2	249	0.0165	Yes	–	–	
15	9.1	0.79	307	279	0.52	4.19	–	8.6	249	0.0165	Yes	57	0.0037	
16	9.2	0.43	306	245	0.30	1.38	–	8.1	249	0.0501	No	–	–	
4	9.1	0.57	306	252	0.37	2.33	–	8.0	249	0.0297	No	–	–	
8	3.3	0.29	252	288	0.68	1.33	0.47	45.4	249	0.0520	Yes	–	–	
1	5.8	0.35	253	261	0.49	1.35	0.89	23.3	249	0.0512	Yes	–	–	
2	7.8	0.41	252	253	0.39	1.52	1.58	13.1	249	0.0455	Yes	–	–	
3	7.9	0.48	253	260	0.41	1.98	2.35	11.1	249	0.0349	Yes	–	–	
6	4.4	0.51	249	258	0.37	1.98	2.78	9.2	249	0.0349	Yes	–	–	1 Cup, No Prop.
4	8.4	0.54	249	257	0.41	2.29	3.13	9.6	249	0.0302	Yes	–	–	
11	7.1	0.60	252	281	0.51	3.13	3.81	11.0	249	0.0221	Yes	–	–	
12	7.9	0.63	251	288	0.48	3.13	4.50	9.5	249	0.0221	Yes	–	–	
13	9.0	0.68	252	281	0.43	3.13	5.33	7.7	249	0.0221	Yes	–	–	1 Cup, No Prop.
14	7.6	0.70	253	298	0.55	4.11	7.05	9.5	249	0.0168	Yes	–	–	
15	8.7	0.76	251	298	0.52	4.11	7.76	8.7	249	0.0168	Yes	–	–	
16	9.6	0.47	253	250	0.30	1.52	2.62	8.1	249	0.0455	No	–	–	
7	9.1	0.57	249	257	0.38	2.29	3.70	8.1	249	0.0302	No	–	–	

Note: 1. Lean Blowout, Unless Otherwise Noted

Table LXIX. Altitude Relight Test Results, Configurations DS1A and DS1B.

Combustor Type - Double Annular   Fuel Injector - As Noted

- All Pilot Stage Injectors Fueled
- Like Configuration II-16 Except Fuel Injectors as Noted

Rdg No.	Simulated Flight Condition Alt. km	Simulated Flight Condition M_p	Combustor Operating Condition T_F K	T_3 K	P_3 atm	W_c kg/s	$\Delta P/P$ %	PT/V atm-K/m/s	Lightoff Attempt W_f (EQUIV) kg/hr	f	Light Off	Blowout Condition (1) W_f (EQUIV) kg/hr	f	Notes
4	3.1	0.29	289	284	0.69	1.35	0.63	46.5	465	0.0953	Yes	-	-	Airblast Injector (DS1A)
1	3.3	0.29	290	287	0.67	1.33	0.66	44.6	463	0.0965	Yes	95	0.0199	
3	6.1	0.35	292	286	0.48	1.35	1.37	22.1	376	0.0773	Yes	-	-	
2	7.3	0.39	292	286	0.40	1.35	2.26	15.8	376	0.0773	Yes	82	0.0168	
7	1.3	0.33	290	286	0.91	2.27	0.83	48.4	376	0.0459	Yes	-	-	
20	3.7	0.39	294	283	0.67	2.27	1.61	26.2	376	0.0459	Yes	163	0.0200	
6	5.7	0.45	293	283	0.54	2.27	2.49	17.1	376	0.0459	Yes	290	0.0366	
5	7.1	0.50	292	285	0.47	2.27	3.34	12.7	376	0.0459	Yes	340	0.0416	
9	4.1	0.48	296	283	0.67	3.24	3.03	18.4	376	0.0322	Yes	204	0.0175	
10	6.6	0.58	291	281	0.54	3.24	4.83	11.8	376	0.0322	Yes	332	0.0284	
11	7.1	0.60	296	281	0.51	3.24	5.27	10.7	376	0.0322	Yes	318	0.0273	
13	5.2	0.59	296	281	0.65	4.11	5.26	13.6	249	0.0169	Yes	139	0.0094	
14	8.0	0.73	294	283	0.54	4.11	8.06	9.2	249	0.0169	Yes	123	0.0083	
15	8.3	0.74	294	283	0.53	4.11	8.28	8.9	249	0.0169	Yes	158	0.0107	
16	5.7	0.74	291	285	0.76	5.30	6.69	14.5	249	0.0130	Yes	164	0.0086	
17	8.4	0.88	292	283	0.68	5.29	7.95	11.6	249	0.0132	Yes	154	0.0081	
18	9.4	0.94	292	286	0.65	5.29	8.65	10.6	249	0.0132	Yes	156	0.0082	
21	8.3	0.41	292	286	0.35	1.35	-	12.2	-	-	-	376	0.0773	2
22	9.0	0.56	292	285	0.45	2.27	-	11.5	-	-	-	376	0.0459	2
23	6.8	0.59	296	281	0.53	3.24	-	11.3	-	-	-	376	0.0322	2
24	8.7	0.77	294	283	0.52	4.11	-	8.7	-	-	-	249	0.0169	2
25	>11.0	>1.00	292	286	0.60	5.29	-	8.9	-	-	-	249	0.0131	2
8	1.2	0.26	290	283	0.90	1.35	0.37	78.5	463	0.0953	No	-	-	
5	1.3	0.26	286	296	0.89	1.44	0.43	72.0	249	0.0484	Yes	33	0.0063	9 kg/hr nozzles (DS1B)
8	3.2	0.29	287	294	0.68	1.44	0.76	42.1	249	0.0481	Yes	49	0.0094	
6	7.5	0.39	287	296	0.40	1.44	2.48	14.3	249	0.0484	Yes	-	-	
2	7.6	0.39	286	293	0.39	1.51	2.62	13.2	249	0.0461	Yes	104	0.0191	
7	1.3	0.33	287	292	0.90	2.26	0.90	47.7	249	0.0308	Yes	71	0.0087	
9	3.6	0.38	287	291	0.68	2.27	3.33	26.8	249	0.0307	Yes	104	0.0127	
10	5.6	0.45	287	291	0.55	2.27	2.52	17.3	249	0.0307	Yes	116	0.0142	
12	7.0	0.50	287	291	0.47	2.27	3.47	13.0	249	0.0307	Yes	117	0.0143	
4	9.1	0.57	286	291	0.38	2.27	5.43	8.2	249	0.0[illegible]7	Yes	122	0.0150	
19	1.3	0.40	287	292	0.92	3.20	1.64	35.1	249	0.0218	Yes	120	0.0104	
20	4.0	0.47	287	292	0.68	3.20	3.15	19.0	249	0.0218	Yes	127	0.0111	
21	8.4	0.68	287	292	0.43	3.20	8.24	7.7	249	0.0218	Yes	-	-	
11	1.9	0.49	287	284	0.94	4.28	2.65	27.0	249	0.0162	Yes	122	0.0079	
13	5.5	0.63	287	283	0.65	4.24	5.78	13.0	249	0.0164	Yes	122	0.0080	
14	8.9	0.79	292	290	0.54	4.24	8.83	9.1	249	0.0164	Yes	125	0.0082	
15	10.6	0.92	290	288	0.52	4.25	9.55	8.5	249	0.0125	Yes	117	0.0077	
16	5.4	0.72	292	286	0.78	5.46	6.73	14.6	249	0.0127	Yes	147	0.0075	
17	8.4	0.88	291	284	0.68	5.46	8.95	11.2	249	0.0127	Yes	120	0.0061	
18	9.4	0.94	295	296	0.65	5.40	9.88	10.4	249	0.0126	Yes	134	0.0069	
14	>10.7	>1.00	292	290	0.47	4.24	-	7.0	-	-	-	249	0.0164	2
23	9.3	0.44	287	293	0.30	1.51	4.47	8.0	249	0.0421	No	-	-	
22	9.6	0.59	287	292	0.35	2.26	5.18	7.2	249	0.0308	No	-	-	

Note:
1. Lean Blowout, Unless Otherwise Noted
2. Pressure Blowout

Table LXX. Altitude Relight Test Results, Configuration DS2A, DS2B, DS2C and DS2D.

Combustor Type - Double Annular   Fuel Injector - As Noted

- All Pilot Stage Injectors Fueled
- Like Configuration D4, Except Fuel Injectors as Noted

	Simulated Flight Condition		Combustor Operating Condition						Lightoff Attempt			Blowout Condition (1)		
Rdg No.	Alt. km	M_p	T_F K	T_3 K	P_3 atm	W_c kg/s	ΔP/P %	PT/V atm-K/m/s	W_f (EQUIV) kg/hr	f	Light Off	W_f (EQUIV) kg/hr	f	Notes
18	1.0	0.26	292	297	0.93	1.47	0.3	77.1	249	0.0471	Yes	30	0.0056	9 kg/hr nozzles (DS2A)
24	3.4	0.30	293	301	0.68	1.47	0.6	41.4	249	0.0473	Yes	46	0.0087	
23	7.2	0.37	293	300	0.42	1.47	1.6	15.3	249	0.0473	Yes	117	0.0221	
22	9.1	0.43	293	299	0.31	1.47	4.6	8.7	249	0.0473	Yes	122	0.0231	
21	9.8	0.44	291	298	0.28	1.47	3.6	6.9	249	0.0472	Yes	117	0.0221	
14	1.2	0.32	291	294	0.93	2.39	0.7	47.6	249	0.0291	Yes	41	0.0047	
16	9.1	0.56	292	294	0.38	2.39	4.4	7.9	249	0.0291	Yes	136	0.0158	
17	9.4	0.57	294	296	0.37	2.39	5.5	6.6	249	0.0291	Yes	139	0.0162	
9	1.2	0.40	289	291	0.93	3.35	1.3	34.0	249	0.0207	Yes	139	0.0115	
13	7.9	0.62	291	293	0.48	3.35	5.3	9.1	249	0.0208	Yes	147	0.0122	
12	8.5	0.67	290	293	0.45	3.35	6.2	7.8	249	0.0208	Yes	152	0.0127	
1	2.4	0.57	291	286	0.93	5.44	3.4	21.0	249	0.0128	Yes	166	0.0085	
8	8.2	0.87	287	289	0.68	5.42	6.2	11.2	249	0.0128	Yes	166	0.0085	
5	10.0	0.98	288	284	0.63	5.44	7.5	9.6	249	0.0127	Yes	169	0.0086	(4 of 5 cups)
6	10.0	0.98	288	284	0.63	5.47	7.5	9.6	373	0.0189	Yes	169	0.0086	
4	>10.5	>1.0	291	279	0.60	5.50	8.5	8.6	249	0.0127	Yes	182	0.0092	(3 of 5 cups)
25	>11.2	>0.5	292	297	0.21	1.47	-	4.0	-	-	-	249	0.0471	2
26	10.5	0.63	291	294	0.31	2.39	-	5.3	-	-	-	249	0.0291	2
27	>10.5	0.78	289	291	0.35	3.35	-	4.7	-	-	-	249	0.0207	2
28	>10.5	>1.0	291	286	0.50	5.44	-	6.0	-	-	-	249	0.0128	2
20	11.2	0.5	289	298	0.24	1.47	4.8	5.3	249	0.0472	No	-	-	
19	>11.2	>0.5	289	298	0.21	1.47	6.8	4.0	249	0.0472	No	-	-	
15	10.5	0.63	292	295	0.31	2.39	6.7	5.3	249	0.0291	No	-	-	
11	9.4	0.71	290	293	0.42	3.35	7.3	6.7	249	0.0208	No	-	-	
10	>10.5	0.78	290	292	0.35	3.35	10.9	4.7	249	0.0208	No	-	-	
3	>10.5	>1.0	291	279	0.56	5.50	9.7	7.6	249	0.0127	No	-	-	
7	9.8	0.96	288	287	0.56	5.50	9.5	7.7	373	0.0188	No	-	-	
2	>10.5	>1.0	291	284	0.50	5.47	7.3	6.0	249	0.0129	No	-	-	
14	0.9	0.26	292	288	0.94	1.50	0.33	77.3	249	0.0454	Yes	41	0.0076	18 kg/hr nozzles (DS2B)
19	3.4	0.29	294	291	0.67	1.49	0.66	39.3	249	0.0456	Yes	21	0.0086	
18	5.2	0.33	291	288	0.53	1.50	1.06	25.1	249	0.0454	Yes	106	0.0197	
16	9.2	0.43	292	289	0.30	1.50	3.48	8.1	249	0.0454	Yes	166	0.0308	
11	1.1	0.33	289	286	0.94	2.42	0.68	47.8	249	0.0281	Yes	48	0.0055	
13	8.8	0.56	292	288	0.39	2.42	4.51	8.2	249	0.0282	Yes	193	0.0222	
7	1.2	0.39	290	284	0.94	3.39	1.30	34.2	249	0.0200	Yes	182	0.0149	
10	7.7	0.62	293	286	0.49	3.38	5.27	9.2	249	0.0201	Yes	141	0.0116	
9	8.4	0.65	291	284	0.45	3.39	6.12	8.0	249	0.0191	Yes	201	0.0165	
2	2.1	0.55	291	290	0.94	5.45	3.30	21.3	376	0.0191	Yes	245	0.0125	
17	8.8	0.90	290	288	0.67	5.48	6.87	10.9	376	0.0192	Yes	207	0.0106	
6	10.0	0.97	287	282	0.64	5.48	7.76	9.8	376	0.0190	Yes	203	0.0103	
15	10.5	0.49	291	288	0.26	1.50	-	6.4	-	-	-	249	0.0454	2
20	9.9	0.60	289	286	0.34	2.42	-	6.5	-	-	-	249	0.0281	2
21	9.2	0.69	290	284	0.42	3.39	-	6.9	-	-	-	249	0.0200	2
22	>11.0	>1.0	291	290	0.50	5.45	-	6.1	-	-	-	249	0.0191	2
12	9.6	0.59	292	287	0.35	2.42	5.28	6.8	249	0.0281	No	-	-	
8	9.2	0.69	292	284	0.42	3.59	7.22	6.9	376	0.0308	No	-	-	
13	0.8	0.26	292	288	0.95	1.50	0.30	79.6	249	0.0453	Yes	46	0.0086	45 kg/hr nozzles (DS2C)
17	3.2	0.29	292	291	0.68	1.49	0.67	41.0	249	0.0455	Yes	144	0.0268	
16	4.9	0.33	292	291	0.55	1.49	1.03	26.5	249	0.0455	Yes	163	0.0303	
15	8.6	0.42	292	291	0.33	1.49	2.87	9.9	249	0.0455	Yes	174	0.0324	
14	9.3	0.44	293	288	0.30	1.50	3.59	8.0	249	0.0453	Yes	185	0.0343	
9	1.1	0.33	291	288	0.95	2.42	0.68	49.4	249	0.0281	Yes	196	0.0225	
12	8.9	0.56	291	287	0.38	2.42	4.70	8.0	376	0.0431	Yes	190	0.0218	
11	9.6	0.59	290	288	0.35	2.42	5.67	6.7	408	0.0469	Yes	231	0.0266	
5	1.2	0.39	291	293	0.94	3.34	1.29	34.9	249	0.0703	Yes	-	-	
8	8.7	0.67	291	293	0.44	3.34	6.67	7.6	376	0.0312	Yes	183	0.0152	
7	9.6	0.71	291	293	0.41	3.34	7.85	6.5	376	0.0312	Yes	190	0.0158	
1	2.1	0.55	292	294	0.94	5.37	3.22	21.8	376	0.0194	Yes	213	0.0110	
4	10.0	0.97	291	291	0.64	5.40	8.11	9.9	376	0.0193	Yes	192	0.0099	
3	>11.0	>1.0	291	292	0.60	5.39	8.66	8.9	376	0.0193	Yes	256	0.0132	
18	10.0	0.45	292	288	0.27	1.50	-	6.3	-	-	-	249	0.0453	2
19	10.4	0.62	291	288	0.32	2.42	-	5.5	-	-	-	249	0.0281	2
20	10.4	0.75	291	298	0.37	3.34	-	5.5	-	-	-	376	0.0312	2
1	0.9	0.26	257	293	0.94	1.59	0.31	73.4	376	0.0655	Yes	-	-	
2	3.2	0.29	254	274	0.68	1.59	0.65	38.4	375	0.0655	Yes	-	-	
3	6.1	0.35	253	265	0.43	1.59	1.08	18.8	376	0.0655	Yes	-	-	
4	7.6	0.39	253	251	0.39	1.59	1.89	12.6	376	0.0655	Yes	-	-	
6	1.1	0.33	250	268	0.94	2.43	0.65	48.1	376	0.0430	Yes	-	-	
7	3.6	0.38	251	266	0.68	2.43	1.12	25.2	376	0.0430	Yes	-	-	
8	5.6	0.45	251	263	0.65	2.43	1.75	16.3	376	0.0430	Yes	-	-	
11	1.2	0.39	251	277	0.94	3.39	1.32	34.5	376	0.0308	Yes	-	-	
12	4.0	0.47	251	267	0.68	3.39	2.24	18.0	376	0.0308	Yes	-	-	
15	2.1	0.55	252	287	0.94	5.45	3.21	21.4	376	0.0191	Yes	-	-	
16	5.5	0.73	253	287	0.77	5.45	4.95	14.4	376	0.0191	Yes	-	-	
17	8.4	0.88	253	287	0.68	5.45	6.28	11.2	376	0.0191	Yes	-	-	
18	9.4	0.94	253	288	0.65	5.45	6.95	10.4	376	0.0191	Yes	-	-	
5	9.1	0.43	250	244	0.31	1.59	2.77	8.0	376	0.0655	Yes	-	-	
9	8.2	0.54	251	257	0.41	2.43	3.21	9.3	376	0.0430	Yes	-	-	
10	9.5	0.59	249	247	0.36	2.43	4.23	6.9	376	0.0430	Yes	-	-	
13	6.4	0.57	252	268	0.55	3.39	3.61	11.7	376	0.0308	Yes	-	-	
14	9.0	0.68	252	262	0.43	3.39	5.94	7.2	544	0.0447	Yes	-	-	
21	3.	0.30	289	296	0.66	1.48	0.71	38.8	376	0.0702	Yes	133	0.0249	Airblast Injector (DS2D)
23	5	0.33	291	292	0.53	1.49	1.12	24.6	376	0.0699	Yes	285	0.0532	
26	7.4	0.39	290	292	0.40	1.49	1.98	14.0	376	0.0699	Yes	367	0.0684	
25	8.0	0.40	290	292	0.36	1.49	2.43	11.7	376	0.0699	Yes	354	0.0659	
9	1.1	0.33	288	308	0.94	2.34	0.72	49.8	472	0.0549	Yes	95	0.0113	
11	7.7	0.52	288	306	0.44	2.35	3.61	10.8	472	0.0547	Yes	291	0.0354	
10	8.4	0.54	287	307	0.41	3.24	4.27	9.3	472	0.0549	Yes	395	0.0468	
2	1.2	0.39	285	300	0.94	3.31	1.29	35.1	376	0.0315	Yes	256	0.0215	
4	2.2	0.41	284	300	0.82	3.31	1.72	27.0	472	0.0388	Yes	264	0.0221	
7	6.6	0.58	286	306	0.54	3.27	4.36	11.6	472	0.0394	Yes	389	0.0331	
6	8.1	0.63	283	305	0.47	3.28	5.41	9.0	472	0.0392	Yes	435	0.0369	
5	8.8	0.67	282	302	0.44	3.28	6.49	7.7	472	0.0392	Yes	435	0.0368	
17	2.1	0.55	289	302	0.94	5.31	3.27	21.9	249	0.0128	Yes	225	0.0118	
19	8.8	0.91	295	302	0.67	5.30	6.90	11.1	376	0.0197	Yes	-	-	
18	10.0	0.97	295	302	0.64	5.30	7.61	10.0	376	0.0197	Yes	168	0.0088	
24	8.0	0.40	290	292	0.36	1.49	-	11.7	-	-	-	249	0.0456	2
13	4.4	0.41	288	306	0.62	2.35	-	21.7	-	-	-	249	0.0290	2
12	7.0	0.49	288	306	0.47	2.35	-	12.5	-	-	-	376	0.0444	2
27	9.2	0.87	288	308	0.37	2.34	-	7.8	-	-	-	472	0.0549	2
28	2.5	0.48	285	300	0.79	3.31	-	24.8	-	-	-	376	0.0315	2
29	9.6	0.71	284	300	0.41	3.31	-	6.5	-	-	-	472	0.0388	2
30	>11.0	>1.0	289	302	0.54	5.31	-	7.2	-	-	-	249	0.0128	2
14	0.9	0.26	288	303	0.94	1.46	0.29	79.6	472	0.0878	No	-	-	

Note: 1. Lean Blowout, Unless Otherwise Noted
2. Pressure Blowout

Table LXXI. Altitude Relight Test Results, Configuration DS3.

Combustor Type - Double Annular   Fuel Injector - Std. Production Nozzles

- All pilot stage injections fueled
- Like configuration D1 except for pilot swirlers

Rdg No.	Simulated Flight Condition		Combustor Operating Condition						Lightoff Attempt			Blowout Condition (1)		Notes
	Alt. km	M_p	T_F K	T_3 K	P_3 atm	W_c kg/s	$\Delta P/P$ %	PT/V atm-K/m/s	W_f (EQUIV) kg/hr	f	Light-off	W_f (EQUIV) kg/hr	f	
12	0.9	0.26	291	292	0.94	1.36	0.25	85.8	249	0.0502	Yes	68	0.0139	
16	3.3	0.29	294	294	0.67	1.85	0.51	43.6	249	0.0503	Yes	68	0.0140	
15	5.1	0.33	294	294	0.54	1.35	0.78	27.9	249	0.0503	Yes	79	0.0162	
13	2.6	0.39	293	294	0.39	1.35	1.68	14.7	249	0.0503	Yes	82	0.0168	
14	8.2	0.41	293	294	0.35	1.35	1.97	12.3	249	0.0503	Yes	82	0.0168	
9	1.1	0.33	292	289	0.94	2.36	0.69	49.4	249	0.0289	Yes	82	0.0096	
11	8.1	0.53	296	292	0.42	2.34	3.73	10.0	249	0.0290	Yes	117	0.0139	
10	8.8	0.56	294	291	0.39	2.38	4.49	8.5	249	0.0289	Yes	106	0.0125	
1	1.1	0.39	291	286	0.94	3.24	1.33	35.8	249	0.0209	Yes	101	0.0086	
3	8.0	0.64	288	283	0.47	3.25	5.46	9.0	249	0.0209	Yes	125	0.0107	
4	8.8	0.67	288	283	0.44	3.25	6.50	7.8	249	0.0209	Yes	125	0.0107	
5	2.1	0.55	291	284	0.94	5.48	3.63	21.2	249	0.0124	Yes	144	0.0073	
7	8.8	0.91	289	284	0.67	5.47	7.53	10.8	249	0.0124	Yes	175	0.0089	
6	10.1	0.98	291	288	0.64	5.47	8.38	9.7	249	0.0124	Yes	173	0.0088	
8	12.0	>1.0	289	287	0.59	5.46	9.92	8.4	408	0.0203	Yes	185	0.0094	
17	8.9	0.42	298	294	0.32	1.35	-	10.1	-	-	-	245	0.0503	2
18	9.6	0.59	292	291	0.35	2.36	-	7.1	-	-	-	245	0.0289	2
19	10.5	0.75	291	286	0.37	3.25	-	5.6	-	-	-	245	0.0209	2
20	13.5	>1.0	291	284	0.56	5.48	-	7.4	-	-	-	244	0.0124	2
2	9.6	0.71	293	283	0.41	3.26	7.61	6.6	249	0.0209	No	-	-	

Notes:
1. Lean Blowout, Unless Otherwise Noted
2. Pressure Blowout

Table LXXII. Altitude Relight Test Results, Configuration DS4.

Combustor Type - Double Annular   Fuel Injector - Std. Production Nozzles

- All pilot stage injectors fueled
- Like configuration D4 except for pilot swirlers

Rdg No.	Simulated Flight Condition		Combustor Operating Condition						Lightoff Attempt			Blowout Condition (1)		Notes
	Alt. km	M_p	T_F K	T_3 K	P_3 atm	W_c kg/s	$\Delta P/P$ %	PT/V atm-K/m/s	W_f (EQUIV) kg/hr	f	Light-off	W_f (EQUIV) kg/hr	f	
12	0.9	0.26	296	293	0.94	1.34	0.34	87.1	249	0.0508	Yes	55	0.0113	
16	3.3	0.29	292	296	0.67	1.34	0.81	44.3	249	0.0509	Yes	68	0.0141	
15	5.1	0.33	292	294	0.54	1.34	1.35	28.4	249	0.0509	Yes	60	0.0124	
14	7.6	0.39	296	294	0.39	1.34	2.77	15.0	249	0.0509	Yes	60	0.0124	
13	8.9	0.42	296	294	0.32	1.34	3.73	10.3	249	0.0509	Yes	60	0.0124	
9	1.1	0.33	296	294	0.94	2.34	0.78	49.9	249	0.0291	Yes	82	0.0097	
11	8.4	0.54	295	293	0.41	2.32	4.89	9.4	249	0.0293	Yes	117	0.0140	
10	9.1	0.57	296	294	0.37	2.33	6.02	7.9	249	0.0292	Yes	117	0.0140	
1	1.2	0.39	293	289	0.94	3.20	1.45	36.4	249	0.0212	Yes	104	0.0090	
3	8.0	0.64	295	287	0.47	3.21	6.49	9.2	249	0.0212	Yes	104	0.0090	
2	8.8	0.67	294	287	0.44	3.21	7.29	8.0	249	0.0212	Yes	100	0.0087	
4	1.2	0.39	296	287	0.94	3.26	4.07	21.6	249	0.0126	Yes	62	0.0053	
8	8.8	0.90	290	287	0.67	5.45	8.50	10.9	249	0.0125	Yes	131	0.0067	
7	10.0	0.97	290	287	0.64	5.45	9.48	9.8	249	0.0125	Yes	120	0.0061	
6	11.2	>1.0	291	287	0.61	5.45	10.78	8.9	249	0.0125	Yes	120	0.0061	
5	12.6	>1.0	291	286	0.57	5.45	12.12	8.0	249	0.0125	Yes	112	0.0057	
17	8.9	0.42	296	293	0.32	1.34	-	10.3	-	-	-	249	0.0508	2
18	9.9	0.60	296	293	0.34	2.34	-	6.5	-	-	-	249	0.0291	2
19	9.6	0.71	293	289	0.41	3.20	-	6.8	-	-	-	249	0.0291	2
20	14.2	>1.0	296	287	0.54	5.40	-	9.1	-	-	-	249	0.0216	2

Notes:
1. Lean Blowout, Unless Otherwise Noted
2. Pressure Blowout

Table LXXIII. Altitude Relight Test Results, Configuration DS5A, DS5B, and DS5C.

Combustor Type - Double Annular Fuel Injector - As Noted

- All pilot stage injectors fueled
- Like configuration D5 except has preprototype primary swirler (CS2)

Rdg No.	Simulated Flight Condition		Combustor Operating Condition						Lightoff Attempt			Blowout Condition(1)		Notes
	Alt. km	M_p	T_F K	T_3 K	P_3 atm	W_c kg/s	$\Delta P/P$ %	PT/V atm-K/m/s	W_f (EQUIV kg/hr	f	Light Off	W_f (EQUIV) kg/hr	f	
28	0.5	0.26	286	280	1.02	1.41	0.24	97.2	209	0.0482	Yes	60	0.0118	9 kg/hr Nozzles (DS5A)
14	3.5	0.30	290	281	0.65	1.41	0.52	39.9	249	0.0482	Yes	68	0.0134	
12	6.7	0.37	290	281	0.44	1.41	1.40	18.1	249	0.0482	Yes	68	0.0134	
10	8.2	0.41	290	281	0.36	1.41	2.41	11.9	249	0.0482	Yes	66	0.0129	
24	0.9	0.34	286	280	0.99	2.32	0.63	55.8	249	0.0294	Yes	82	0.0098	
6	7.6	0.52	290	280	0.44	2.32	3.38	11.2	249	0.0294	Yes	82	0.0098	
8	8.2	0.54	290	280	0.42	2.32	4.36	9.9	249	0.0294	Yes	102	0.0122	
20	0.8	0.40	286	278	1.01	3.28	1.20	40.6	249	0.0208	Yes	89	0.0074	
4	7.7	0.62	290	288	0.49	3.25	5.40	9.6	249	0.0210	Yes	102	0.0087	
1	9.7	0.71	290	283	0.40	3.25	8.28	6.6	249	0.0210	Yes	123	0.0105	
30	1.1	0.52	286	279	1.05	5.58	3.14	25.9	249	0.0122	Yes	149	0.0074	
16	5.2	0.71	286	278	0.78	5.60	5.89	14.5	249	0.0121	Yes	149	0.0074	
18	9.5	0.94	286	278	0.65	5.46	8.19	10.2	249	0.0125	Yes	171	0.0087	
12	0.8	0.26	286	279	0.96	1.38	0.25	88.9	249	0.0494	Yes	102	0.0206	18 kg/hr Nozzles (DS5B)
11	6.1	0.35	286	278	0.48	1.32	1.03	22.6	249	0.0514	Yes	143	0.0300	
7	8.5	0.41	286	278	0.34	1.38	1.73	11.1	249	0.0494	Yes	103	0.0208	
6	10.3	0.46	286	277	0.25	1.33	4.09	6.0	249	0.0510	Yes	102	0.0213	
13	1.0	0.33	286	279	0.97	2.20	0.59	56.4	249	0.0308	Yes	137	0.0173	
5	7.3	0.51	286	277	0.46	2.23	3.01	12.3	249	0.0305	Yes	109	0.0136	
4	8.6	0.55	286	277	0.40	2.23	4.46	9.3	249	0.0305	Yes	88	0.0110	
10	10.5	0.62	286	277	0.31	2.20	-	6.0	249	0.0306	Yes	103	0.0129	
14	1.0	0.39	286	278	0.98	3.15	1.18	40.3	249	0.0216	Yes	137	0.0121	
3	8.3	0.65	286	277	0.45	3.15	5.66	8.9	249	0.0216	Yes	119	0.0105	
2	9.7	0.71	286	276	0.40	3.14	7.55	6.7	249	0.0217	Yes	117	0.0104	
15	1.3	0.52	286	278	1.0	5.32	3.24	25.5	249	0.0128	Yes	157	0.0082	
9	7.9	0.86	286	276	0.69	5.40	7.36	11.8	249	0.0126	Yes	163	0.0084	
8	10.5	1.0	286	276	0.62	5.35	9.24	9.6	249	0.0127	Yes	170	0.0088	
30	0.7	0.26	241	296	0.99	1.36	0.25	94.4	249	0.0449	Yes	204	0.0416	
17	7.5	0.39	240	290	0.40	1.39	2.48	14.8	249	0.0481	Yes	177	0.0352	
16	7.5	0.39	240	290	0.40	1.39	2.48	14.8	249	0.0489	Yes	163	0.0326	Facility Limit
18	9.5	0.44	248	289	0.29	1.39	3.26	8.2	249	0.0490	Yes	-	-	No Prop. Fac. Lim.
27	0.8	0.34	238	295	1.00	2.25	0.67	58.3	321	0.0340	Yes	212	0.0262	
13	5.1	0.43	245	289	0.58	2.28	2.00	19.6	249	0.0298	Yes	139	0.0169	
15	7.8	0.52	243	290	0.44	2.31	3.83	10.8	249	0.0294	Yes	239	0.0284	
14	7.9	0.53	252	290	0.43	2.35	3.88	10.4	249	0.0290	Yes	217	0.0257	Facility Limit
3	0.9	0.40	257	283	1.00	3.25	1.30	40.7	376	0.0321	Yes	150	0.0128	
7	4.1	0.48	253	286	0.68	3.16	2.76	19.1	249	0.0215	Yes	147	0.0129	
22	4.2	0.48	243	294	0.67	3.20	3.06	18.3	249	0.0213	Yes	144	0.0125	
9	7.5	0.61	243	289	0.50	3.24	5.92	10.0	249	0.0210	Yes	136	0.0120	
10	7.5	0.61	243	289	0.50	3.24	5.92	10.0	249	0.0210	Yes	137	0.0117	Facility Limit
21	9.3	0.69	243	293	0.42	3.19	8.38	7.3	249	0.0213	Yes	135	0.0118	
25	1.1	0.52	243	295	1.05	5.43	3.27	26.5	249	0.0125	Yes	154	0.0079	
12	7.9	0.86	242	289	0.69	5.37	8.47	11.8	249	0.0127	Yes	147	0.0076	
11	>11.0	>1.0	237	289	0.60	5.41	11.19	8.9	249	0.0126	Yes	164	0.0084	
22	0.9	0.26	252	303	0.94	1.33	0.27	87.8	249	0.0510	Yes	136	0.0284	14 kg/hr Nozzles (DS5C)
8	3.1	0.29	252	272	0.69	1.36	0.50	45.5	249	0.0502	Yes	163	0.0334	
1	6.1	0.35	252	260	0.47	1.43	0.98	20.7	249	0.0474	Yes	177	0.0342	
2	7.6	0.39	252	251	0.39	1.40	1.62	14.2	249	0.0486	Yes	185	0.0367	
23	9.2	0.43	252	242	0.30	1.39	2.46	8.8	249	0.0491	Yes	211	0.0423	
21	1.1	0.33	252	304	0.94	2.29	0.78	51.1	249	0.0297	Yes	177	0.0214	
6	5.7	0.45	252	272	0.55	2.32	2.17	16.8	249	0.0293	Yes	211	0.0752	
5	7.0	0.49	251	261	0.47	2.33	2.74	12.7	249	0.0292	Yes	196	0.0233	
24	8.4	0.54	252	256	0.41	2.36	3.91	8.8	305	0.0359	Yes	210	0.0247	
20	1.1	0.39	252	304	0.94	3.15	1.38	37.2	249	0.0216	Yes	188	0.0166	
10	6.5	0.57	253	272	0.52	3.16	4.52	10.9	305	0.0268	Yes	286	0.0251	
11	7.1	0.60	252	272	0.52	3.16	4.52	10.9	305	0.0268	Yes	286	0.0251	
12	9.0	0.68	251	262	0.48	3.17	6.60	7.6	359	0.0315	Yes	267	0.0234	
19	2.0	0.55	752	304	0.94	5.31	3.95	22.1	249	0.0128	Yes	197	0.0103	
16	6.1	0.75	252	303	0.75	5.38	6.37	14.0	249	0.0128	Yes	191	0.0019	
17	8.5	0.88	252	303	0.68	5.31	8.01	11.4	249	0.0128	Yes	210	0.0110	
18	9.4	0.94	252	303	0.65	5.31	8.78	10.6	249	0.0128	Yes	231	0.0121	
25	9.8	0.45	252	272	0.28	1.36	1.24	7.5	-	-	-	249	0.0502	2
26	9.9	0.60	252	256	0.34	2.36	4.68	6.5	-	-	-	305	0.0359	2
27	9.4	0.70	251	262	0.42	3.17	6.81	7.2	-	-	-	359	0.0315	2
28	9.1	0.68	253	272	0.43	3.17	5.29	7.5	-	-	-	245	0.0215	2
29	>11.0	>1.0	252	303	0.57	5.33	-	7 9	-	-	-	245	0.0128	2
4	9.1	0.57	251	251	0.37	2.33	-	7.9	249	0.0292	No	-	-	
22	8.9	0.42	252	244	0.32	1.33	-	10.4	305	0.0648	No	-	-	
21	9.6	0.71	252	261	0.41	3.16	-	6.9	463	0.0406	No	-	-	

Notes:
1. Lean Blowout, Unless Otherwise Noted
2. Pressure Blowout

Table LXXIV. Altitude Relight Test Results, Configuration DS19.

Combustor Type - Double Annular   Fuel Injector - 14 kg/hr Prototype Nozzles

- All pilot stage injectors fueled
- Like configuration D7 except has preprototype primary swirler (CS2)

Rdg No.	Simulated Flight Condition		Combustor Operating Condition						Lightoff Attempt			Blowout Condition(1)		Notes
	Alt. km	M_p	T_F K	T_3 K	P_3 atm	W_c kg/s	$\Delta P/P$ %	PT/V atm-K/m/s	W_f (EQUIV) kg/hr	f	Light Off	W_f (EQUIV) kg/hr	f	
7	1.2	0.39	298	299	0.93	3.17	1.53	36.0	267	0.0234	Yes	231	0.0203	
9	6.4	0.57	298	299	0.55	3.18	3.81	12.3	305	0.0266	Yes	217	0.0190	
8	7.9	0.63	298	296	0.48	3.17	5.08	9.6	376	0.0329	Yes	199	0.0174	
3	2.3	0.56	301	301	0.93	5.32	4.40	21.3	332	0.0173	Yes	238	0.0124	
5	5.8	0.74	298	299	0.76	5.33	6.46	14.4	381	0.0199	Yes	232	0.0121	
4	10.3	0.99	298	300	0.63	5.33	9.61	9.8	286	0.0149	Yes	278	0.0145	
10	8.9	0.68	298	299	0.44	3.17	-	7.6	-	-	-	267	0.0234	2
2	>11.0	>1.0	301	301	0.60	5.32	-	8.8	-	-	-	376	0.0196	2

Notes:
1. Lean Blowout, Unless Otherwise Noted
2. Pressure Blowout

Table LXXV. Altitude Relight Test Results, Configuration DS20.

Combustor Type - Double Annular   Fuel Injector - 14 kg/hr Prototype Nozzles

- All pilot stage injectors fueled
- Like configuration D7 except has preprototype primary swirler (CS2) and no pilot dilution

Rdg No.	Simulated Flight Condition		Combustor Operating Condition						Lightoff Attempt			Blowout Condition(1)		Notes
	Alt. km	M_p	T_F K	T_3 K	P_3 atm	W_c kg/s	$\Delta P/P$ %	PT/V atm-K/m/s	W_f (EQUIV) kg/hr	f	Light Off	W_f (EQUIV) kg/hr	f	
11	0.9	0.26	299	309	0.94	1.32	0.25	88.1	249	0.0515	Yes	95	0.0200	
14	3.3	0.29	298	309	0.67	1.32	0.59	44.7	249	0.0516	Yes	101	0.0212	
13	5.0	0.33	298	309	0.54	1.32	1.01	28.6	249	0.0516	Yes	136	0.0286	
12	9.5	0.44	298	309	0.29	1.32	0	8.3	249	0.0515	Yes	131	0.0286	
8	1.1	0.33	301	304	0.94	2.27	0.76	51.3	249	0.0300	Yes	122	0.0150	
10	9.2	0.57	300	304	0.37	2.26	3.11	8.0	249	0.0300	Yes	155	0.0190	
9	9.9	0.60	299	309	0.34	2.26	3.56	6.7	249	0.0300	Yes	150	0.0184	
5	1.2	0.39	298	308	0.94	3.12	1.49	37.3	249	0.0218	Yes	163	0.0145	
7	8.8	0.67	298	309	0.44	3.12	5.94	8.1	249	0.0218	Yes	163	0.0146	
6	9.6	0.71	298	308	0.41	3.12	7.04	6.9	249	0.0218	Yes	177	0.0158	
1	2.1	0.55	298	304	0.94	5.28	4.26	22.0	249	0.0129	Yes	169	0.0082	
4	8.7	0.90	300	308	0.67	5.26	8.53	11.3	249	0.0129	Yes	169	0.0089	
3	9.9	0.97	298	307	0.64	5.27	9.49	10.2	249	0.0129	Yes	167	0.0088	
2	>10.7	>1.0	300	306	0.61	5.28	10.66	9.2	249	0.0129	Yes	169	0.0089	
15	9.5	0.44	299	309	0.29	1.32	-	8.3	-	-	-	249	0.0515	2
16	9.9	0.60	301	309	0.34	2.27	-	6.7	-	-	-	249	0.0300	2
17	9.6	0.71	298	308	0.41	3.12	-	6.9	-	-	-	249	0.0218	2
18	>10.7	>1.0	298	304	0.57	5.28	-	8.2	-	-	-	249	0.0129	2

Notes:
1. Lean Blowout, Unless Otherwise Noted
2. Pressure Blowout

Table LXXVIII. Altitude Relight Test Results, Configuration DS23.

Combustor Type - Double Annular   Fuel Injector - 17 kg/hr Prototype Nozzles

- All Pilot Stage Injectors Fueled
- Like Configuration Except Has Preprototype Primary Swirler (CS2) and Dilution in Fourth Panel

	Simulated Flight Condition		Combustor Operating Condition						Lightoff Attempt			Blowout Condition (1)		
Rdg No.	Alt. km	M_P	T_F K	T_3 K	P_3 atm	W_c kg/s	$\Delta P/P$ %	PT/V atm-K/m/s	W_f (EQUIV) kg/hr	f	Light Off	W_f (EQUIV) kg/hr	f	Notes
12	1.0	0.26	301	298	0.93	1.35	0.28	84.7	249	0.0454	Yes	112	0.0230	
13	9.4	0.44	301	298	0.30	1.35	3.23	8.6	249	0.0516	Yes	122	0.0252	
9	1.2	0.33	301	298	0.93	2.31	0.82	49.4	249	0.0262	Yes	150	0.0180	
11	9.7	0.59	301	298	0.35	2.31	6.52	6.8	249	0.0301	Yes	109	0.0131	
6	1.2	0.39	301	298	0.93	3.18	1.46	35.9	249	0.0209	Yes	133	0.0121	
8	9.9	0.72	301	297	0.40	3.18	8.98	6.5	249	0.0219	Yes	134	0.0117	
2	2.2	0.55	301	302	0.93	5.32	4.04	21.5	249	0.0121	Yes	163	0.0085	
5	9.1	0.92	301	297	0.66	5.36	8.70	10.7	249	0.0119	Yes	174	0.0090	
4	<11.0	<1.0	301	297	0.61	5.36	10.29	9.3	249	0.0119	Yes	154	0.0088	
15	9.4	0.44	301	298	0.30	1.35	---	8.6	---	---	---	251	0.0516	2
14	10.9	0.64	301	298	0.30	2.31	---	5.3	---	---	---	251	0.0301	2
7	10.7	0.76	301	297	0.36	3.18	---	5.5	---	---	---	250	0.0219	2
10	10.6	0.62	301	298	0.31	2.31	8.16	5.6	249	0.0301	No	---	---	

Notes:
1. Lean Blowout, Unless Otherwise Noted
2. Pressure Blowout

Table LXXIX. Altitude Relight Test Results, Configuration DS24.

Combustor Type - Double Annular   Fuel Injector - 17 kg/hr Prototype Nozzles

- All Pilot Stage Injectors Fueled
- Like Configuration D8 Except Has Preprototype Primary Swirler (CS2) and Dilution in First and Second Panels

	Simulated Flight Condition		Combustor Operating Condition						Lightoff Attempt			Blowout Condition (1)		
Rdg No.	Alt. km	M_P	T_F K	T_3 K	P_3 atm	W_c kg/s	$\Delta P/P$ %	PT/V atm-K/m/s	W_f (EQUIV) kg/hr	f	Light Off	W_f (EQUIV) kg/hr	f	Notes
3	1.2	0.39	301	296	0.93	3.19	1.45	35.6	318	0.0277	Yes	256	0.0223	
1	2.2	0.55	301	300	0.93	5.33	4.13	21.3	329	0.0172	Yes	274	0.0143	
4	9.7	0.95	301	300	0.65	5.33	----	10.2	---	---	---	251	0.0131	2
2	2.2	0.55	301	300	0.93	5.10	3.73	22.3	354	0.0193	No	---	---	

Notes:
1. Lean Blowout, Unless Otherwise Noted
2. Pressure Blowout

Table LXXVIII. Altitude Relight Test Results, Configuration DS23.

Combustor Type - Double Annular   Fuel Injector - 17 kg/hr Prototype Nozzles

- All Pilot Stage Injectors Fueled
- Like Configuration Except Has Preprototype Primary Swirler (CS2) and Dilution in Fourth Panel

Rdg No.	Simulated Flight Condition		Combustor Operating Condition						Lightoff Attempt			Blowout Condition (1)		Notes
	Alt. km	M_p	T_F K	T_3 K	P_3 atm	W_c kg/s	$\Delta P/P$ %	PT/V atm-K/m/s	W_f (EQUIV) kg/hr	f	Light Off	W_f (EQUIV) kg/hr	f	
12	1.0	0.26	301	298	0.93	1.35	0.28	84.7	249	0.0454	Yes	112	0.0230	
13	9.4	0.44	301	298	0.30	1.35	3.23	8.6	249	0.0516	Yes	122	0.0252	
9	1.2	0.33	301	298	0.93	2.31	0.82	49.4	249	0.0262	Yes	150	0.0180	
11	9.7	0.59	301	298	0.35	2.31	6.52	6.8	249	0.0301	Yes	109	0.0131	
6	1.2	0.39	301	298	0.93	3.18	1.46	35.9	249	0.0209	Yes	133	0.0121	
8	9.9	0.72	301	297	0.40	3.18	8.98	6.5	249	0.0219	Yes	134	0.0117	
2	2.2	0.55	301	302	0.93	5.32	4.04	21.5	249	0.0121	Yes	163	0.0085	
5	9.1	0.92	301	297	0.66	5.36	8.70	10.7	249	0.0119	Yes	174	0.0090	
4	<11.0	<1.0	301	297	0.61	5.36	10.29	9.3	249	0.0119	Yes	154	0.0088	
15	9.4	0.44	301	298	0.30	1.35	---	8.6	---	---	---	251	0.0516	2
14	10.9	0.64	301	298	0.30	2.31	---	5.3	---	---	---	251	0.0301	2
7	10.7	0.76	301	297	0.36	3.18	---	5.5	---	---	---	250	0.0219	2
10	10.6	0.62	301	298	0.31	2.31	8.16	5.6	249	0.0301	No	---	---	

Notes:
1. Lean Blowout, Unless Otherwise Noted
2. Pressure Blowout

Table LXXIX. Altitude Relight Test Results, Configuration DS24.

Combustor Type - Double Annular   Fuel Injector - 17 kg/hr Prototype Nozzles

- All Pilot Stage Injectors Fueled
- Like Configuration D8 Except Has Preprototype Primary Swirler (CS2) and Dilution in First and Second Panels

Rdg No.	Simulated Flight Condition		Combustor Operating Condition						Lightoff Attempt			Blowout Condition (1)		Notes
	Alt. km	M_p	T_F K	T_3 K	P_3 atm	W_c kg/s	$\Delta P/P$ %	PT/V atm-K/m/s	W_f (EQUIV) kg/hr	f	Light Off	W_f (EQUIV) kg/hr	f	
3	1.2	0.39	301	296	0.93	3.19	1.45	35.6	318	0.0277	Yes	256	0.0223	
1	2.2	0.55	301	300	0.93	5.33	4.13	21.3	329	0.0172	Yes	274	0.0143	
4	9.7	0.95	301	300	0.65	5.33	----	10.2	---	---	---	251	0.0131	2
2	2.2	0.55	301	300	0.93	5.10	3.73	22.3	354	0.0193	No	---	---	

Notes:
1. Lean Blowout, Unless Otherwise Noted
2. Pressure Blowout

Table LXXX. Altitude Relight Test Results, Configuration DS28.

Combustor Type - Double Annular   Fuel Injector - 17 kg/hr Prototype Nozzles

- All Pilot Stage Injectors Fueled
- Like Configuration D12A Except Primary Swirler $A_e = 0.733\ cm^2$

Rdg No.	Simulated Flight Condition		Combustor Operating Condition						Lightoff Attempt			Blowout Condition (1)		Notes
	Alt. km	M_p	T_F K	T_3 K	P_3 atm	W_c kg/s	ΔP/P %	PT/V atm-K/m/s	W_f (EQUIV) kg/hr	f	Light Off	W_f (EQUIV) kg/hr	f	
1	0.6	0.26	302	317	0.99	1.32	0.24	98.3	167	0.0352	Yes	76	0.0159	
9	5.5	0.34	302	317	0.51	1.32	1.06	26.1	162	0.0341	Yes	90	0.0190	
8	6.4	0.36	302	317	0.46	1.32	1.27	20.8	172	0.0363	Yes	80	0.0168	
7	8.4	0.41	302	317	0.34	1.32	1.83	11.7	178	0.0375	Yes	66	0.0139	
6	9.2	0.43	302	317	0.31	1.32	2.13	9.3	180	0.0380	Yes	67	0.0142	
15	0.9	0.34	302	314	0.98	2.18	0.56	58.4	167	0.0213	Yes	83	0.0105	
10	6.0	0.46	302	314	0.52	2.18	2.35	16.5	189	0.0241	Yes	86	0.0110	
14	8.3	0.54	302	314	0.41	2.18	3.17	10.2	178	0.0226	Yes	83	0.0106	
13	9.1	0.57	302	314	0.37	2.18	4.13	8.5	167	0.0212	Yes	91	0.0116	
16	0.9	0.40	299	314	0.99	3.09	1.13	41.5	171	0.0154	Yes	112	0.0101	
20	3.1	0.64	299	314	0.47	3.09	5.39	9.4	179	0.0161	Yes	126	0.0113	
19	9.0	0.68	299	314	0.43	3.09	6.54	7.8	193	0.0174	Yes	120	0.0108	
22	1.5	0.53	301	312	1.00	5.23	3.13	25.0	198	0.0105	Yes	149	0.0079	
27	7.9	0.86	301	312	0.69	5.23	6.69	12.1	194	0.0103	Yes	143	0.0076	
26	9.6	0.95	301	312	0.65	5.23	7.88	10.6	183	0.0097	Yes	145	0.0077	
25	<11.0	<1.0	301	312	0.58	5.23	10.31	8.4	203	0.0108	Yes	145	0.0077	
12	10.4	0.62	302	314	0.32	2.18	---	6.2	---	---	---	247	0.0314	2
24	<11.0	<1.0	301	312	0.50	5.23	---	6.3	---	---	---	247	0.0131	2
5	10.0	0.45	302	317	0.27	1.32	3.86	7.1	143	0.0301	No	---	---	
4	10.0	0.61	302	314	0.34	2.18	5.04	6.8	181	0.0230	No	---	---	
18	9.9	0.72	299	314	0.40	3.09	7.63	6.7	191	0.0172	No	---	---	

Notes:
1. Lean Blowout, Unless Otherwise Noted
2. Pressure Blowout

Table LXXXI. Altitude Relight Test Results, Configuration DS29.

Combustor Type - Double Annular Fuel Injector - 17 kg/hr Prototype Nozzles

- All Pilot Stage Injectors Fueled
- Like Configuration D12A

Rdg No.	Simulated Flight Condition		Combustor Operating Condition						Lightoff Attempt			Blowout Condition (1)		Notes
	Alt.	M_p	T_F K	T_3 K	P_3 atm	W_c Kg/s	$\Delta P/P$ %	PT/V atm-K/m/s	W_f (EQUIV) kg/hr	f	Light Off	W_f (EQUIV) kg/hr	f	
37	0.7	0.26	299	313	0.99	1.33	0.22	95.9	173	0.0360	Yes	137	0.0286	
41	8.3	0.41	299	313	0.35	1.33	1.85	12.2	208	0.0432	Yes	120	0.0250	
42	8.7	0.42	299	313	0.33	1.33	5.94	10.8	200	0.0415	Yes	125	0.0261	
31	9.0	0.43	299	313	0.31	1.33	1.89	9.6	212	0.0441	Yes	116	0.0242	
24	0.9	0.34	298	312	0.99	2.23	0.54	58.3	181	0.0225	Yes	---	---	
34	6.1	0.46	298	312	0.52	2.23	2.07	16.1	206	0.0257	Yes	135	0.0169	
33	6.6	0.48	298	312	0.49	2.73	2.09	14.5	205	0.0255	Yes	137	0.0170	
32	7.1	0.50	298	312	0.47	2.23	2.41	13.0	206	0.0258	Yes	133	0.0166	
31	7.6	0.52	298	312	0.44	2.23	2.99	11.6	211	0.0264	Yes	137	0.0170	
30	8.1	0.53	298	312	0.42	2.23	3.28	10.4	239	0.0299	Yes	115	0.0143	
29	8.7	0.55	298	312	0.39	2.23	4.25	9.1	260	0.0324	Yes	---	---	
28	9.1	0.57	298	312	0.37	2.23	5.12	8.3	282	0.0328	Yes	122	0.0153	
13	0.9	0.40	297	308	0.99	3.15	1.17	41.1	204	0.0180	Yes	134	0.0118	
23	5.9	0.55	297	308	0.57	3.15	3.62	13.6	194	0.0171	Yes	135	0.0119	
22	6.5	0.57	297	308	0.54	3.15	4.03	12.4	196	0.0173	Yes	140	0.0123	
21	6.9	0.59	297	308	0.52	3.15	4.33	11.4	208	0.0183	Yes	142	0.0126	
20	7.4	0.61	297	308	0.50	3.15	4.75	10.5	215	0.0110	Yes	137	0.0120	
18	7.8	0.63	297	308	0.48	3.15	5.09	9.8	199	0.0176	Yes	139	0.0122	
18	8.1	0.64	297	308	0.47	3.15	5.62	9.1	198	0.0155	Yes	---	---	
16	9.0	0.68	297	308	0.43	3.15	6.98	7.7	272	0.0240	Yes	---	---	
15	9.7	0.71	297	308	0.40	3.15	7.71	6.7	271	0.0239	Yes	---	---	
1	1.5	0.53	295	302	0.99	5.40	3.22	24.1	209	0.0107	Yes	151	0.0078	
11	8.4	0.88	295	302	0.68	5.40	7.13	11.3	225	0.0116	Yes	151	0.0077	
10	9.0	0.91	295	302	0.66	5.40	7.55	10.8	227	0.0117	Yes	160	0.0082	
9	9.8	0.96	295	302	0.64	5.40	8.32	10.1	275	0.0142	Yes	152	0.0078	
7	10.7	1.0	295	302	0.62	5.40	8.95	9.4	213	0.0110	Yes	---	---	
6	<10.7	<1.0	295	302	0.58	5.40	10.67	8.2	219	0.0112	Yes	177	0.0091	
38	10.2	0.46	299	313	0.26	1.33	---	6.5	---	---	---	249	0.0515	2
27	10.2	0.61	298	312	0.33	2.23	---	6.3	---	---	---	249	0.0308	2
14	10.3	0.74	297	308	0.38	3.15	---	6.0	---	---	---	249	0.0218	2
4	<10.7	<1.0	295	302	0.55	5.40	---	7.3	---	---	---	249	0.0127	2

Notes:
1. Lean Blowout, Unless Otherwise Noted
2. Pressure Blowout

Table LXXXII. Altitude Relight Test Results, Configuration DS30.

Combustor Type - Double Annular Fuel Injector - 17 kg/hr Prototype Nozzles

- All Pilot Stage Injectors Fueled
- Like Configuration D12A Except Primary Swirler A_e = .833 cm^2

Rdg No.	Simulated Flight Condition		Combustor Operating Condition						Lightoff Attempt			Blowout Condition (1)		Notes
	Alt. km	M_p	T_F K	T_3 K	P_3 atm	W_c kg/s	ΔP/P %	PT/V atm-K/m/s	W_f (EQUIV) kg/hr	f	Light Off	W_f (EQUIV) kg/hr	f	
28	1.0	0.26	302	313	0.93	1.34	0.32	85.0	175	0.0364	Yes	37	0.0077	
30	2.2	0.27	302	313	0.77	1.34	0.45	58.7	181	0.0377	Yes	37	0.0077	
32	4.7	0.32	302	313	0.57	1.34	1.08	31.6	175	0.0364	Yes	80	0.0167	
35	9.5	0.44	302	313	0.29	1.34	3.04	8.3	195	0.0406	Yes	81	0.0169	
26	1.1	0.33	302	313	0.94	2.23	0.66	52.7	176	0.0219	Yes	76	0.0095	
20	7.3	0.50	302	313	0.46	2.23	2.83	12.5	171	0.0214	Yes	116	0.0145	
24	8.6	0.55	302	313	0.40	2.23	3.92	9.3	176	0.0220	Yes	105	0.0131	
11	1.1	0.39	304	313	0.95	3.13	0	37.7	176	0.0156	Yes	82	0.0073	
18	6.9	0.59	304	313	0.52	3.13	3.96	11.4	186	0.0165	Yes	105	0.0093	
16	8.3	0.65	304	313	0.46	3.13	4.96	8.9	199	0.0176	Yes	106	0.0094	
15	9.0	0.68	304	313	0.43	3.13	6.49	7.7	195	0.0173	Yes	104	0.0092	
3	1.1	0.52	305	313	1.05	5.31	3.01	27.2	199	0.0104	Yes	134	0.0070	
10	5.6	0.73	305	313	0.77	5.31	5.83	14.6	191	0.0100	Yes	134	0.0070	
9	6.7	0.78	305	313	0.73	5.31	6.53	13.3	181	0.0095	Yes	118	0.0062	
7	10.5	1.0	305	313	0.63	5.31	9.06	9.7	208	0.0109	Yes	118	0.0062	
5	>10.7	>1.0	305	313	0.58	5.31	10.79	8.4	225	0.0118	Yes	128	0.0067	
23	9.4	0.58	302	313	0.36	2.23	-	7.7	-	-	Yes	249	0.0308	2
34	10.1	0.46	302	313	0.26	1.34	7.35	6.7	247	0.0513	No	-	-	
13	9.8	0.71	304	313	0.40	3.13	7.75	6.7	247	0.0219	No	-	-	
15	0.8	0.25	300	308	0.99	1.36	0.2	95.4	173	0.353	Yes	151	0.0307	
33	4.9	0.32	302	313	0.56	1.33	1.1	31.6	247	0.0233	Yes	150	0.0311	
10	8.2	0.40	300	306	0.36	1.36	1.8	13.0	170	0.0346	Yes	152	0.0311	
11	9.4	0.43	300	306	0.30	1.36	2.7	9.2	166	0.0340	Yes	147	0.0299	
13	10.1	0.45	300	306	0.26	1.36	3.6	6.9	169	0.0345	Yes	145	0.0297	
17	0.9	0.32	300	308	0.99	2.23	0.6	58.4	172	0.0214	Yes	136	0.0169	
5	6.7	0.47	301	305	0.49	2.26	2.8	14.0	176	0.0217	Yes	169	0.0208	
28	7.6	0.52	303	311	0.43	2.23	3.8	10.8	167	0.0208	Yes	156	0.0195	
6	7.9	0.53	300	305	0.42	2.26	4.0	10.4	176	0.0216	Yes	168	0.0207	
24	9.8	0.58	302	313	0.38	2.23	5.7	8.6	170	0.0212	Yes	111	0.0138	
19	0.9	0.37	300	308	1.01	3.16	1.2	42.5	181	0.0159	Yes	123	0.0108	
34	4.7	0.50	303	302	0.64	3.18	3.1	16.9	182	0.0159	Yes	173	0.0151	
2	7.3	0.60	300	302	0.53	3.18	5.4	10.0	185	0.0161	Yes	172	0.0150	
35	9.4	0.70	304	313	0.43	3.13	6.5	7.7	215	0.0191	Yes	104	0.0092	
22	1.2	0.53	302	309	1.05	5.33	3.1	26.9	194	0.0101	Yes	184	0.0096	
32	6.1	0.74	303	302	0.73	5.42	6.4	13.3	193	0.0099	Yes	163	0.0084	
30	9.8	0.97	303	300	0.63	5.42	9.1	9.8	201	0.0103	Yes	158	0.0081	
23	10.3	0.65	302	313	0.36	2.23	-	7.7	-	-	Yes	249	0.0311	2
14	10.4	0.77	304	313	0.39	1.15	7.8	6.8	249	0.0221	No	-	-	
11	1.1	0.26	243	307	0.94	1.31	0.2	87.7	249	0.0521	Yes	41	0.0086	
10	6.1	0.35	238	257	0.48	1.31	0.8	22.4	249	0.0526	Yes	122	0.0258	
9	7.6	0.38	226	249	0.39	1.31	1.3	15.0	249	0.0527	Yes	136	0.0286	
12	1.2	0.33	248	308	0.93	2.29	0.7	50.2	249	0.0305	Yes	101	0.0123	
7	7.0	0.48	244	262	0.48	2.26	2.5	13.1	249	0.0307	Yes	117	0.0144	
13	1.5	0.40	242	309	0.93	3.10	1.4	36.2	249	0.0224	Yes	182	0.0163	
5	6.4	0.56	241	274	0.54	3.10	3.6	12.7	249	0.0244	Yes	199	0.0178	
1	7.9	0.86	248	308	0.68	5.25	7.6	11.5	249	0.0132	Yes	191	0.0101	
2	9.1	0.93	243	311	0.65	5.23	8.3	10.7	367	0.0195	Yes	204	0.0108	
8	8.5	0.53	244	258	0.40	2.26	3.4	9.3	367	0.0451	No	-	-	
6	7.9	0.62	244	268	0.48	3.10	4.8	9.6	408	0.0365	No	-	-	

Notes:
1. Lean Blowout, Unless Otherwise Noted
2. Pressure Blowout

Table LXXXIII. Idle Emissions Test Results, Swirl Cup Investigation.

Configuration Number	Pilot Stage[1] Features			Emission Index,[2] g/kg @ f =													
	Fuel Nozzle Type	Primary Swirler Type	Secondary Mixing Section	.008		.009		.010		.011		.012		.013		.015	
				CO	HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	HC
DS3	Standard Production CF6-50	B5	No	–	–	77.1	49.5	68.8	35.6	66.2	24.9	68.0 67.6	26.2 25.7	70.1	16.5	–	–
DS4	Standard Production CF6-50	B5, 25% Reduced Flowrate	No	80.5	50.4	71.2	34.9	71.3	25.3	74.7	18.9	–	–	77.6	12.4	–	–
DS5A	Prototype	Prototype	Yes	48.3	12.5	–	–	40.0	3.0	39.8 39.5	2.4 1.7	48.1	1.4	–	–	–	–
DS5B	Development	Prototype	Yes	–	–	48.0	14.5	–	–	35.9	5.0	–	–	36.8	2.0	48.7	0.8
DS6	Development	Development	Yes	–	–	37.6	8.1	39.7	7.4	35.7 37.7	5.2 3.8	36.3	3.0	42.1	2.4	–	–
DS7	Development	Development	No	–	–	68.0	35.0	–	–	67.0	35.0	–	–	69.0	31.0	–	–

(1) Double Annular Combustor Like D5 Except as Noted

(2) $P_3 = 2.91$ atm
$T_3 = 429$ K
$V_R = 18.3$ m/s

Table LXXXIV. Idle Emissions Test Results, Fuel Nozzle Investigation*.

Test Rig	Configuration Number	First Outer Cooling Ring Flow % W_c	Pilot Stage Fuel Nozzle Type	Emission Index, g/kg, @ f = .008		.009		.010		.011		.012		.013		.014	
				CO	HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	HC
Full Annular	D12A	1%	Annular Prototype Std.	30.3	14.1	22.5	10.0	21.2	8.1	24.5	7.3	30.5	6.8	38.0	6.5	46.0	6.1
	D12B	1%	Unshrouded Simplex	23.7	6.5	19.0	4.5	18.1	2.9	22.0	2.8	26.0	2.6	34.0	2.7	44.3	3.0
	D14A	3%	Unshrouded Simplex	34.8	9.2	30.0	6.2	26.8	4.5	26.4	3.1	32.0	3.0	38.0	3.0	45.9	3.3
	D14B	3%	Annular Prototype Std.	49.3	31.0	44.0	26.8	43.7	21.7	48.4	18.8	53.5	17.1	62.0	15.9	71.0	15.0
60° Sector	DS31A (Like D12A)	1%	Annular Prototype Std.	–	–	21.2	7.8	25.8	7.6	28.9	5.1	34.2	4.2	–	–	–	–
	DS31B	1%	Annular Prototype Mod. Shroud Air Closed	29.2	6.3	24.5	5.0	24.9	5.2	26.2	4.5	25.8	3.1	32.6	2.8	–	–
	DS31C (Like D12B)	1%	Unshrouded Simplex	20.6	4.4	19.2	3.6	20.2	3.2	23.5	3.1	28.2	2.7	30.1	2.0	–	–
	DS31D	1%	Sector Prototype	61.1	14.2	25.4	3.1	19.9	2.3	18.6	0.9	18.9	0.5	20.1	0.3	–	–
	DS32A	2% (Engine Design)	Annular Prototype Mod. 62° Spray Angle	37.5	9.0	30.8	6.4	25.2	4.8	24.1	3.7	28.3	3.5	32.4	3.1	–	–
	DS32B	2%	Unshrouded Simplex	–	–	21.4	2.6	20.0	2.0	20.1	2.1	25.9	3.2	32.9	4.6	–	–
	DS33A (Like D14A Pilot)	3%	Unshrouded Simplex	40.1	6.5	31.9	4.9	25.0	3.9	26.0	3.7	27.9	3.4	36.6	4.8	–	–
	DS33B	3%	Annular Prototype Mod. 62° Spray Angle	29.8	5.0	21.6 21.7	5.8 4.3	21.9	7.2	25.9 25.0	3.3 6.5	28.6	7.1	31.9 36.0	4.7 4.1	–	–
	DS33C (Like D14B Pilot)	3%	Annular Prototype Std. 48° Spray Angle	53.5	17.5	39.1	13.2	33.1	10.9	26.5	7.2	26.5 27.9	5.7 6.1	33.3	8.2	–	–
	DS33D	3%	Same, Max Radial & Max Axial Immersion	101.9	56.0	74.4	32.7	39.6	11.4	27.9	7.3	27.2	6.0	30.0	4.4	–	–
	DS33E	3%	Same, Max Radial & Min Axial Immersion	48.8	22.4	35.4	16.5	27.1	11.4	22.5	8.8	21.5	6.2	26.5	6.8	–	–

*Double Annular Combustor
P_3 = 2.91 atm
T_3 = 429 K
V_R = 18.3 m/s

Table LXXXV. Idle Emissions Test Results, Airflow Investigation[1].

Test Rig	Conf. No.	Airflow, % W_c				Emission Index[2] g/kg, @ f =																	
		1st Outer Cool.	2nd Outer Dil.	4th Outer Dil.	4th Inner Dil.	0.008		0.009		0.010		0.011		0.012		0.013		0.014		0.015		0.016	
						CO	HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	HC	CO	HC
Full Annular	D12B	1.0	4.5	0	4.4	23.7	6.5	19.0	4.5	18.1	2.9	22.0	2.8	26.0	2.6	34.0	2.7	44.3	3.0	–	–	–	–
	D13	1.0	4.5	0	4.4	34.3	9.5	27.0	5.0	21.8	3.0	19.0	2.2	21.8	2.0	32.0	2.0	49.0	2.5	–	–	–	–
	D14A	3.0	4.5	0	4.4	34.8	9.2	30.0	6.2	26.8	4.5	26.4	3.1	32.0	3.0	38.0	3.0	45.9	3.3	–	–	–	–
60° Sector	DS31C	1.0	4.5	0	4.4	20.6	4.4	19.2	3.6	20.2	3.2	23.5	3.1	28.2	2.7	30.1	2.0	–	–	–	–	–	–
	DS32B	2.0	4.5	0	4.4			21.4	2.6	20.0	2.0	20.1	2.1	25.9	3.2	32.9	4.6	–	–	–	–	–	–
	DS33A	3.0	4.5	0	4.4	40.1	6.5	31.9	4.9	25.0	3.9	26.0	3.7	27.9	3.4	36.6	4.8	–	–	–	–	–	–
	DS34	3.0	4.5	2.0	4.4	29.3	5.6	25.2	4.6	23.4	3.9	24.1	3.9	25.0	3.5	28.4	3.4	32.2	2.9	34.9	2.4	37.9	2.8
												24.1	3.2					32.6	2.6				
	DS35	3.0	4.5	2.0	0	27.3	3.5	23.6	2.6	21.6	1.8	21.9	1.6	21.3	1.4	24.5	1.4	29.3	1.7	31.3	1.5	34.8	1.5
	DS36	3.0	4.5	0	0	26.3	3.6	22.4	2.7	20.4	2.0	21.1	1.7	22.6	1.6	27.3	1.8	30.9	1.8	35.8	2.1	37.4	1.8
	DS37	3.0	6.5	0	0	27.4	3.3	22.0	2.4	19.4	1.8	18.4	1.4	21.0	1.4	24.8	1.5	28.8	1.6	31.0	1.6	34.2	1.5

(1) Double Annular Combustor
Unshrouded Simplex Fuel Nozzles
Engine Prototype Pilot Stage Swirlers

(2) P_3 = 2.91 atm
T_3 = 429 K
V_R = 18.3 m/s

Table LXXXVI. Subidle Temperature Rise Test Results.

Configuration	Simulated RPM	W_c (EQUIV) kg/s	T3 K	P3 Atm	Temperature Rise, K, at f = 0.0150	0.0175	0.0200	0.0225	0.0250	0.0275	0.0300	0.0325	0.0350
DS34	3000	4.52	300	1.22	–	392	530	649	751	–	–	–	–
	3500	5.50	294	1.37	242	409	558	704	781	817	868	909	941
	4000	6.34	301	1.55	414	646	732	782	825	–	–	–	–
DS35	3500	5.50	286	1.35	271	439	564	632	767	884	935	979	1014
DS36	3500	5.50	297	1.36	235	444	647	805	819	926	961	981	995
Standard Production Combustor (Reference)	3500	5.50	294	1.37	328	428	528	628	736	767	778	778	778

Table LXXXVII. Cross-Fire Test Results, Airflow Investigation*.

Config.	Main Stage Airflow Distribution (%W_c)(1)				Crossfire Slot	Main Stage Fuel-Air Ratio							
						Full Propagation						Lean Blowout	
						T_3 = 630 K, f_{Pilot} =			T_3 = 533 K, f_{Pilot} =			f_{Pilot} = 0.010, T_3 =	
	Primary Swirler	Secondary Swirler	Dome Holes	Inner Liner Holes		0.005	0.010	0.015	0.005	0.010	0.015	630 K	533 K
DS8	9.2	37.1	0	4.2(1st Panel)	No	0.030	0.027	0.023	---	---	---	0.015	---
DS9	9.1	37.0	0	0	No	0.029	0.025	0.022	0.032	0.028	0.031	0.017	0.020
DS10	3.4	28.9	0	0	No	0.025	0.022	0.018	0.032	0.031	0.031	0.005	0.009
DS11	9.1	28.8	0	8.4(1st Panel)	No	No Light	0.028	---	---	---	---	0.015	---
DS12	9.1	28.8	0	8.4(2nd Panel)	No	---	0.025	0.023	---	---	---	0.018	---
DS13	3.4	28.7	0	8.3(2nd Panel)	No	0.027	0.022	0.019	---	---	---	0.004	---
DS14	3.4	28.7	0	8.3(1st Panel)	No	0.030	0.028	0.021	---	---	---	0.004	---
DS15	3.4	36.9	0	8.4(1st Panel)	No	0.028	0.026	0.026	---	---	---	0.019	---
DS16	3.5	28.9	4.8	10.6(1st Panel)	No	0.024	0.024	0.023	---	0.025	---	0.006	0.008
DS17	3.5	28.9	4.8	10.6(1st Panel)	Yes	0.017	0.017	0.017	0.025	0.024	---	0.005	0.008
DS18	3.5	29.0	0	10.6(1st Panel)	Yes	0.015	0.015	0.015	0.024	0.022	0.018	0.005	0.007

*60° Sector Double Annular Combustor Like Configuration D6 Except as Noted

P_3 = 1.1 atm

V_R = 23.2 m/s at 630 K, 20.0 m/s at 533 K

(1) Pilot Stage Cup Flow = 12.2-13/8% W_C

Pilot Stage Dilution Flow = 3.1-4.6% W_C

Table LXXXVIII. Cross-Fire Test Results, Slot Geometry Investigation*.

Configuration Number	Crossfire Slot Geometry		Main Stage Fuel-Air Ratio for Full Propagation								
	Axial Length cm	Circumferential Width cm	f pilot = 0.005 T_3 =			f pilot = 0.010 T_3 =			f pilot = 0.015 T_3 =		
			429 K	520 K	630 K	429 K	520 K	630 K	429 K	520 K	630 K
DS25	3.9 (2)	2.5 (2)	0.030	0.021	0.017	0.025	0.019	0.016	0.023	0.022	0.016
DS27	3.9	1.2	>0.030	0.030	0.020	>0.030	0.030	0.018	>0.030	0.030	0.018
DS26	2.7	2.5	>0.030	0.021	0.018	>0.030	0.020	0.020	>0.030	0.020	0.018
DS22	0	0	>0.030	>0.030	>0.030	>0.030	>0.030	>0.030	>0.030	>0.030	>0.030

(1) 60° Sector Double Annular Combustor Like Full Annular Configuration D8 Except for Slot Geometry Changes

P_3 = 1.1 atm

V_R = 23.2 m/s @630 K, 19.5 m/s @520 K, 1913 m/s @429 K

(2) Like DS17, 18 & Full Annular D8-14

Table LXXXIX. Altitude Relight Test Results, Configuration RS1A and RS1B.

Combustor Type - Radial/Axial Staged Fuel Injector - As Noted

- All Pilot Stage Injectors Fueled
- Like Configuration R2 Except Fuel Injectors as Noted

Rdg No.	Simulated Flight Condition Alt. km	Simulated Flight Condition M_p	Combustor Operating Condition T_F K	T_3 K	P_3 atm	W_c kg/s	$\Delta P/P$ %	PT/V atm-K/m/s	Lightoff Attempt W_f (EQUIV) kg/hr	f	Light Off	Blowout Condition(1) W_f (EQUIV) kg/hr	f	Notes
19	1.2	0.38	288	288	0.95	2.93	0.92	40.6	373	0.0354	Yes	297	0.0281	Airblast Injector (RS1A)
23	4.7	0.48	288	290	0.63	2.92	2.26	18.0	373	0.0355	Yes	250	0.0238	
21	5.2	0.50	288	289	0.60	2.93	2.47	16.1	373	0.0354	Yes	250	0.0238	
12	1.6	0.46	289	286	0.95	4.03	1.72	29.4	373	0.0257	Yes	248	0.0171	
17	3.5	0.53	288	287	0.76	4.03	2.69	19.1	373	0.0257	Yes	278	0.0192	
14	4.0	0.55	287	286	0.73	4.03	2.95	17.5	272	0.0187	Yes	218	0.0150	
2	2.0	0.53	288	279	0.95	5.01	8.90	6.9	373	0.0207	Yes	231	0.0126	
10	8.0	0.81	289	283	0.63	5.02	5.88	10.4	373	0.0206	Yes	185	0.0108	
7	>10.7	>1.0	288	281	0.60	5.03	6.58	9.3	373	0.0206	Yes	191	0.0105	
25	5.8	0.52	288	288	0.56	2.93	-	14.3	-	-	-	373	0.0354	2
26	4.3	0.56	289	286	0.71	4.03	-	16.6	-	-	-	373	0.0257	2
27	>10.7	>1.0	288	278	0.48	5.07	-	6.0	-	-	-	373	0.0204	2
24	0.9	0.29	288	291	0.95	1.68	0.34	70.4	463	0.0764	No	-	-	
17	0.9	0.26	291	303	0.94	1.47	0.39	79.7	249	0.0464	Yes	68	0.0129	18 kg/hr Nozzles (RS1B)
21	3.3	0.29	293	302	0.67	1.47	0.66	40.5	249	0.0464	Yes	84	0.0160	
20	5.1	0.33	293	303	0.54	1.47	1.01	26.0	249	0.0464	Yes	117	0.0222	
19	7.2	0.38	292	303	0.41	1.47	1.75	14.9	249	0.0464	Yes	150	0.0284	
18	7.9	0.40	291	303	0.37	1.47	2.04	12.6	249	0.0464	Yes	155	0.0294	
9	1.1	0.33	291	300	0.94	2.37	0.82	49.3	376	0.0440	Yes	68	0.0080	
10	5.4	0.44	288	302	0.56	2.37	2.25	17.3	376	0.0440	Yes	163	0.0191	
11	6.0	0.46	288	302	0.52	2.37	2.58	15.3	376	0.0440	Yes	171	0.0201	
12	6.7	0.48	289	303	0.49	2.36	2.93	13.5	376	0.0442	Yes	176	0.0208	
13	7.3	0.51	289	302	0.46	2.36	3.44	11.7	376	0.0442	Yes	176	0.0208	
14	8.0	0.53	290	303	0.42	2.36	3.94	10.0	376	0.0442	Yes	186	0.0218	
2	1.1	0.39	289	280	0.94	3.42	1.46	34.2	376	0.0305	Yes	106	0.0086	
7	6.2	0.56	287	281	0.56	3.36	4.27	12.2	249	0.0202	Yes	-	-	
6	6.9	0.59	287	281	0.52	3.36	4.78	10.8	249	0.0202	Yes	183	0.0151	
5	7.6	0.62	287	281	0.49	3.42	5.60	9.3	462	0.0375	Yes	139	0.0113	
23	2.1	0.55	293	288	0.94	5.46	3.76	21.4	376	0.0191	Yes	189	0.0096	
25	4.2	0.65	291	285	0.82	5.46	4.98	16.4	376	0.0191	Yes	163	0.0083	
27	7.6	0.84	290	285	0.70	5.47	6.95	11.9	376	0.0191	Yes	-	-	
28	8.8	0.90	293	283	0.67	5.48	7.81	10.8	376	0.0191	Yes	-	-	
30	8.5	0.41	291	303	0.34	1.47	-	10.4	-	-	-	249	0.0464	2
31	8.4	0.54	291	300	0.41	2.37	-	9.2	-	-	-	376	0.0440	2
15	10.9	0.64	290	303	0.30	2.36	-	4.9	-	-	-	249	0.0288	2
16	9.5	0.58	290	303	0.36	2.36	-	7.1	-	-	-	340	0.0400	2
32	9.9	0.72	289	280	0.39	3.42	-	5.9	-	-	-	376	0.0305	2
29	>11.0	>1.0	293	283	0.52	5.48	-	6.6	-	-	-	249	0.0124	2
24	>11.0	>1.0	291	288	0.51	5.46	-	6.2	-	-	-	376	0.0191	2
4	8.3	0.65	287	281	0.46	3.42	6.55	8.1	462	0.0375	No	-	-	
3	9.1	0.69	289	281	0.42	3.42	7.53	6.9	462	0.0376	No	-	-	

Notes:
1. Lean Blowout, Unless Otherwise Noted
2. Pressure Blowout

Table XC. Altitude Relight Test Results, Configuration RS2A and RS2B.

Combustor Type – Radial/Axial Staged   Fuel Injector – 18 kg/hr Nozzles

- All Pilot Stage Injectors Fueled
- Like Configuration R3 Except Ignitor as Noted

Rdg No.	Simulated Flight Condition: Alt. km	Simulated Flight Condition: M_p	Combustor Operating Condition: T_F K	T_3 K	P_3 atm	W_c kg/s	ΔP/P %	PT/V atm-K/m/s	Lightoff Attempt: W_f (EQUIV) kg/hr	f	Light Off	Blowout Condition (1): W_f (EQUIV) kg/hr	f	Notes
17	0.8	0.26	291	289	0.96	1.39	0.23	88.1	249	0.0489	Yes	–	–	Upstream Ignitor (RS2A)
22	4.1	0.31	291	291	0.61	1.39	0.63	34.8	249	0.0491	Yes	143	0.0286	
21	6.6	0.37	290	290	0.44	1.43	1.55	18.1	249	0.0477	Yes	161	0.0313	
20	7.9	0.40	290	290	0.37	1.39	–	13.2	249	0.0489	Yes	–	–	
18	8.7	0.42	291	289	0.33	1.39	–	10.3	249	0.0489	Yes	142	0.0283	
10	1.0	0.33	291	289	0.98	2.16	0.48	57.6	376	0.0481	Yes	103	0.0132	
16	5.7	0.45	289	289	0.55	2.16	1.80	18.2	249	0.0314	Yes	207	0.0265	
13	7.8	0.52	290	289	0.44	2.16	2.87	11.6	249	0.0314	Yes	198	0.0253	
1	0.9	0.40	291	290	0.99	3.23	1.12	39.8	249	0.0210	Yes	218	0.0187	
15	3.5	0.45	291	289	0.71	3.26	2.27	20.6	249	0.0209	Yes	198	0.0169	
7	5.1	0.51	291	289	0.62	3.26	3.19	15.4	249	0.0209	Yes	197	0.0168	
6	5.5	0.53	292	291	0.59	3.37	3.79	13.6	249	0.0202	Yes	177	0.0146	
23	1.3	0.52	291	289	1.02	5.49	2.91	25.1	249	0.0124	Yes	182	0.0092	
25	8.4	0.88	291	287	0.68	5.47	6.57	11.2	376	0.0191	Yes	169	0.0086	
11	9.7	0.59	291	289	0.35	2.17	–	7.3	–	–	–	376	0.0481	2
8	9.7	0.71	291	289	0.40	3.26	–	6.6	–	–	–	375	0.0320	2
19	9.2	0.43	291	289	0.31	1.39	–	8.9	249	0.0489	No	–	–	
14	9.2	0.58	291	289	0.37	2.19	4.72	8.2	376	0.0477	No	–	–	
4	8.2	0.65	292	293	0.46	3.21	5.73	8.8	376	0.0325	No	–	–	
5	6.7	0.58	292	290	0.53	3.24	4.36	11.4	376	0.0322	No	–	–	
24	>11.0	>1.0	291	287	0.59	5.42	8.73	8.6	376	0.0192	No	–	–	
11	9.3	0.44	291	287	0.30	1.41	2.46	8.4	249	0.0482	Yes	211.0	0.0415	Downstream Ignitor (RS2B)
9	10.1	0.61	291	287	0.33	2.17	4.54	6.6	249	0.0314	Yes	200.0	0.0256	
10	10.6	0.62	291	287	0.31	2.17	5.25	6.0	249	0.0314	Yes	201.5	0.0258	
5	0.9	0.40	291	287	0.99	3.18	1.02	40.1	249	0.0214	Yes	210.9	0.0184	
8	8.4	0.65	291	287	0.46	3.20	5.33	8.6	249	0.0213	Yes	194.7	0.0169	
7	10.4	0.74	291	287	0.38	3.22	8.02	5.8	249	0.0211	Yes	196.2	0.0169	
1	1.2	0.52	291	286	1.03	5.52	2.88	25.1	249	0.0123	Yes	186.7	0.0094	
4	7.6	0.84	291	286	0.70	5.52	6.53	11.8	249	0.0123	Yes	188.6	0.0095	
3	11.2	>1.0	292	286	0.61	5.52	8.[illegible]0	8.8	249	0.0123	Yes	198.6	0.0100	
6	10.7	0.76	291	287	0.36	3.18	–	5.5	–	–	–	245.3	0.0214	2
2	15.5	>1.0	291	286	0.51	5.51	–	6.3	–	–	–	245.9	0.0124	Facility Limit

Notes:
1. Lean Blowout, Unless Otherwise Noted
2. Pressure Blowout

Table XCI. Altitude Relight Test Results, Configuration RS3.

Combustor Type - Radial/Axial Staged Fuel Injector - 18 kg/hr Nozzles

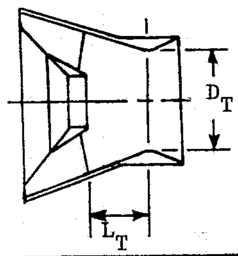
- All Pilot Stage Injectors Fueled
- Like Configuration R5 Except has 60 Flameholders

Rdg No.	Simulated Flight Condition		Combustor Operating Condition						Lightoff Attempt			Blowout Condition (1)		Notes
	Alt. km	M_p	T_F K	T_3 K	P_3 atm	W_c kg/s	ΔP/P %	PT/V atm-K/m/s	W_f (EQUIV) kg/hr	f	Light Off	W_f (EQUIV) kg/hr	f	
1	1.0	0.26	298	298	0.93	1.35	0.20	85.2	249	0.0515	Yes	68	0.0140	Downstream Ignitor
5	3.4	0.29	298	298	0.66	1.35	0.41	43.0	249	0.0516	Yes	73	0.0150	
4	5.2	0.33	298	298	0.53	1.35	0.42	27.5	249	0.0516	Yes	85	0.0174	
3	8.6	0.42	298	298	0.33	1.35	0.20	10.9	249	0.0516	Yes	114	0.0235	
2	9.3	0.44	298	298	0.30	1.35	0.10	8.8	249	0.0516	Yes	134	0.0275	
6	1.2	0.33	298	297	0.93	2.32	0.60	49.7	249	0.0300	Yes	98	0.0117	
8	7.5	0.51	298	296	0.45	2.32	1.80	11.5	249	0.0300	Yes	130	0.0157	
7	8.1	0.54	298	297	0.42	2.32	2.06	9.9	249	0.0300	Yes	127	0.0153	
10	1.2	0.39	298	296	0.93	3.18	1.13	36.2	249	0.0218	Yes	131	0.0114	
12	7.0	0.52	298	295	0.52	3.18	3.18	11.1	249	0.0218	Yes	136	0.0119	
11	7.8	0.63	298	295	0.48	3.18	3.66	9.7	249	0.0218	Yes	139	0.0121	
13	2.2	0.55	298	295	0.94	5.37	3.18	21.4	249	0.0130	Yes	149	0.0077	
15	9.0	0.91	298	294	0.66	5.37	6.21	10.8	249	0.0129	Yes	141	0.0073	
14	10.1	0.98	298	294	0.63	5.37	6.90	9.9	249	0.0129	Yes	141	0.0073	
16	9.3	0.44	298	298	0.30	1.35	-	8.8	-	-	-	251	0.0516	2
17	8.1	0.54	298	297	0.42	2.32	-	9.9	-	-	-	250	0.0300	2
18	7.8	0.63	298	295	0.48	3.18	-	9.7	-	-	-	250	0.0218	2
19	10.1	0.98	298	294	0.63	5.37	-	9.9	-	-	-	249	0.0129	2

Notes:

1. Lean Blowout, Unless Otherwise Noted
2. Pressure Blowout

Table XCII. Carboning Test Results.



- 12° Sector Rig, Boattail Shrouded Fuel Nozzle
- 4.5 Hour Test Cycle with Heavy Distillate Fuel

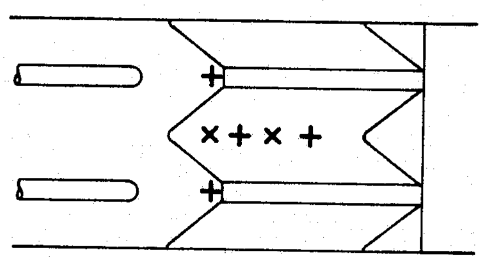
Swirler Assembly Configuration Number	CS1*	CS2	CS3	CS4	CS5	CS6	CS7	CS8	CS9
Primary Swirler									
A_{es}, Effective Flow Area, cm^2	0.645	0.535	0.535	0.755	0.755	0.755	0.923	0.735	0.838
Swirl Angle, degrees from axial	60	57.5	57.5	37	37	37	37	37	37
Venturi									
L_T, Throat length, cm	1.19	1.52	1.19	1.93	1.19	1.02	1.02	1.02	1.02
D_T, Throat diameter, cm	1.91	1.91	1.57	1.73	1.57	1.73	1.73	1.73	1.73
Design Ratios									
A_{es}/A_T	0.226	0.188	0.275	0.322	0.387	0.322	0.386	0.314	0.358
L_T/D_T	0.63	0.80	0.76	1.12	0.76	0.59	0.59	0.59	0.59
Posttest Inspection Results									
Carbon on Fuel Nozzle?	Yes	Yes	No	No	No	No	No	No	No
Carbon on Venturi?	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No

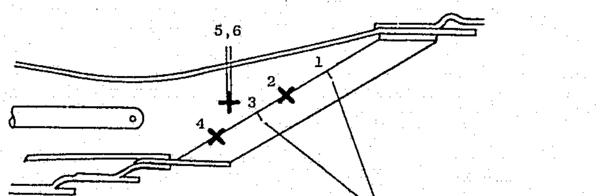
*Development Design for Airblast Fuel Injectors, Carbon Tested in another Program.

Table XCIII. Flashback Test Results, Configuration FS1.

• Like Configuration R3 Except Premix Length of 10.2 cm

Reading Number	Fuel Type	Inlet Air		Fuel-Air Ratio			Pressure Loss		(Temperature)-(Inlet Temperature), K					
									Flameholders*				Air*	
		Pressure Atm	Temperature K	Pilot	Main	Overall	%	Actual/Design	1	2	3	4	5	6
1	JP-5	9.7	775	0.004	--	0.004	3.94	1.05	449	131	484	147	-2	-4
2	JP-5	10.1	778	0.004	0.022	0.026	3.78	1.10	422	105	461	125	-263	-249
3	JP-5	9.6	776	0.006	--	0.006	3.96	1.06	776	224	768	222	1	1
4	JP-5	9.5	776	0.006	0.020	0.026	4.02	1.05	763	205	756	209	-253	-240
5	JP-5	11.8	815	0.004	--	0.004	3.21	1.02	--	124	--	--	2	2
6	JP-5	9.5	815	0.004	0.022	0.026	3.98	1.00	--	108	--	--	-275	-157
7	JP-5	9.5	816	0.006	--	0.006	4.01	1.01	--	198	--	--	-1	-2
8	JP-5	11.8	814	0.006	0.020	0.026	3.25	0.98	--	188	--	--	-265	-262
9	JP-5	9.5	815	0.008	--	0.008	4.00	1.00	--	252	--	--	0	0
10	JP-5	9.6	815	0.008	0.018	0.026	3.90	0.98	--	253	--	--	-251	-256
11	JP-5	9.6	777	0.008	--	0.008	3.83	0.96	--	293	--	--	-2	-3
12	JP-5	9.5	765	0.008	0.018	0.026	3.93	0.96	--	270	--	--	-242	-177
13	JP-5	12.9	810	0.004	--	0.004	4.00	0.99	--	137	--	--	1	0
14	JP-5	12.9	817	0.004	0.022	0.026	3.87	0.97	--	124	--	--	-256	-238
15	JP-5	12.8	814	0.006	--	0.006	4.02	0.94	--	198	--	--	1	2
16	JP-5	12.9	811	0.006	0.020	0.026	4.00	0.98	--	197	--	--	-246	-246
17	JP-5	12.9	811	0.008	--	0.008	3.98	0.97	--	255	--	--	2	0
18	JP-5	13.0	810	0.008	0.018	0.026	3.98	0.97	--	246	--	--	-244	-236
19	JP-5	15.0	829	0.004	--	0.004	3.88	1.02	--	122	--	--	2	--
20	JP-5	15.0	829	0.004	0.022	0.024	3.94	1.03	--	97	--	--	-255	-238
21	JP-5	15.2	825	0.006	--	0.006	--	--	--	12	--	--	6	--
22	JP-5	15.2	825	0.006	0.020	0.026	4.31	1.05	--	120	--	--	-238	-224
23	JP-5	14.8	831	0.008	--	0.008	--	--	--	10	--	--	1	--
24	JP-5	14.8	831	0.008	0.018	0.026	3.95	0.99	--	54	--	--	-244	-188



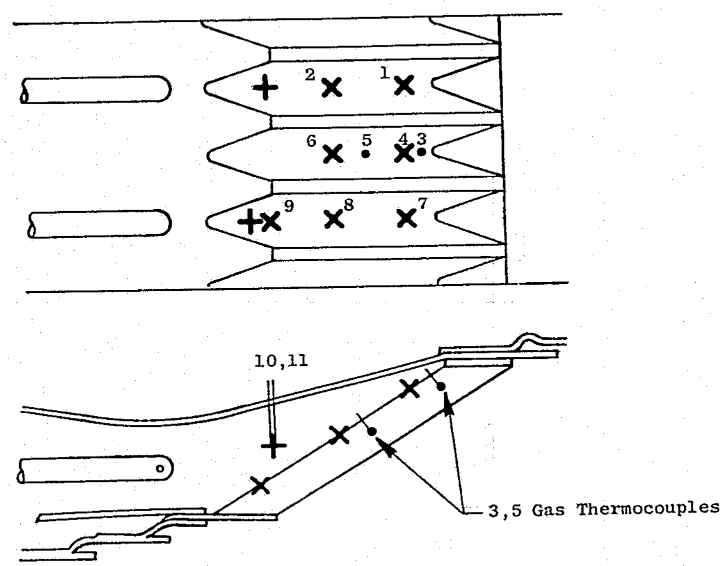


* Thermocouple Locations

Table XCIV. Flashback Test Results, Configuration FS2.

- Like Configuration R5 Except Premix Length = 10.2 cm

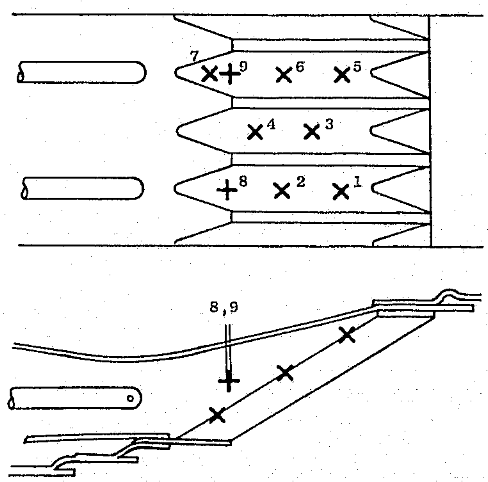
Reading Number	Fuel Type	Inlet Air		Fuel-Air Ratio			Pressure Loss		(Temperature)-(Inlet Temperature) K										
									Flameholders*									Air*	
		Pressure atm	Temperature K	Pilot	Main	Overall	%	Actual/Design	1	2	3	4	5	6	7	8	9	10	11
1	JP-5	4.8	726	0.004	0.017	0.021	3.75	1.17	45	47	409	-132	322	118	-	-143	88	-41	-27
2	JP-5	4.8	730	0.008	0.017	0.025	3.75	1.05	-95	-45	226	-166	205	79	-	-186	48	-33	-18
3	JP-5	4.8	781	0.004	0.019	0.023	3.80	1.09	-67	-21	227	-188	205	79	-	-192	39	-43	-36
4	JP-5	4.8	785	0.008	0.019	0.027	3.66	1.05	21	27	441	-134	362	139	-	-129	98	-36	-27
5	JP-5	4.7	806	0.004	0.019	0.023	3.77	1.07	-54	-12	227	-182	204	79	-	-190	33	-30	-22
6	JP-5	4.8	805	0.008	0.019	0.027	3.71	1.07	41	46	434	-140	336	129	-	-105	86	-27	-20
7	JP-5	9.5	820	0.004	0.022	0.026	3.96	0.98	24	49	259	-162	255	94	-	-19	52	-50	-43
8	JP-5	9.5	820	0.008	0.018	0.026	4.06	0.93	134	136	483	-81	410	158	-	54	118	-41	-22
9	JP-5	12.9	823	0.004	0.022	0.026	4.00	1.00	34	34	63	-127	249	91	-	38	78	-56	-34
10	JP-5	12.9	822	0.008	0.018	0.026	3.95	0.93	134	154	601	-23	540	221	-	156	167	-38	-41
11**	JP-5	16.3	818	0.004	0.022	0.026	3.98	0.76	97	131	333	333	325	131	-	56	105	-22	-37
12	JP-5	9.6	824	0.008	0.018	0.026	4.04	0.48	184	204	615	-19	592	250	-	84	167	-41	-56
13	JP-5	12.9	821	0.008	0.018	0.026	4.02	0.42	164	203	634	-10	594	257	-	80	171	-56	-37
14	JP-5	11.8	834	0.008	0.018	0.026	3.52	0.42	170	179	638	4	599	264	-	92	172	-37	-31



* Thermocouple Locations
** Pressure Drop Indicates Liner Failure Occurred at this Condition

Table XCV. Flashback Test Results, Configuration FS3.

Reading Number	Fuel Type	Inlet Air		Fuel-Air Ratio			Pressure Loss		(Temperature)-(Inlet Temperature), K									SAE Smoke Number
									Flameholders*							Air*		
		Pressure Atm	Temperature K	Pilot	Main	Overall	%	Act/ Des.	1	2	3	4	5	6	7	8	9	
1	JP-5	3.0	434	0.0045	0	0.0045	--	--	292	274	272	229	174	131	132	-6	-6	--
2		11.8	632	0.0041	0	0.0041	3.87	1.03	108	106	91	90	68	11	58	-12	-10	--
3		9.7	820	0.0037	0	0.0037	3.92	0.99	87	87	72	78	58	-79	58	-24	-24	--
4		9.7	822	0.0037	0.0177	0.0214	3.90	0.99	12	2	79	89	-27	-65	50	-21	-53	--
5		9.7	820	0.0075	0.0140	0.0215	3.78	0.95	144	131	187	190	43	-15	102	-23	-71	--
6	Blend B	9.7	820	0.0037	0.0176	0.0213	4.06	1.01	29	20	69	81	-26	-45	44	-74	-56	--
7		9.6	820	0.0077	0.0144	0.0221	3.76	0.99	127	113	198	201	49	-32	103	-59	-78	--
8		9.6	822	0.0038	0	0.0038	4.02	1.02	106	120	82	94	68	-2	81	-21	-11	--
9		13.0	824	0.0039	0	0.0039	3.92	0.93	108	122	88	102	71	49	81	-13	-11	--
10		13.2	819	0.0037	0.0178	0.0215	3.87	1.01	16	17	72	83	-19	-148	58	-25	-39	--
11		13.0	823	0.0075	0.0144	0.0219	3.86	0.99	152	144	201	211	70	-43	135	-38	-54	4.9
12		16.1	830	0.0041	0	0.0041	3.73	1.01	104	113	76	84	58	17	64	-13	-13	--
13 **		16.2	825	0.0053	0.0151	0.0204	2.82	0.77	67	54	64	117	23	0	69	-18	-32	--
14		16.1	823	0.0078	0.0145	0.0223	3.62	0.93	-36	149	66	206	151	-6	117	-22	-34	6.3
15		16.5	821	0.0059	0.0166	0.0225	3.25	0.84	227	219	175	180	133	2	122	-22	-10	--
16	JP-5	15.9	825	0.0079	0.0140	0.0219	3.44	0.88	Out	206	100	204	190	50	87	-104	-33	--
17		16.1	826	0.0080	0.0148	0.0228	3.33	0.87	Out	219	129	224	203	26	79	-77	-43	5.6
18		15.6	829	0.0079	0.0149	0.0228	3.65	0.87	Out	202	62	179	223	-21	77	-56	-39	--
19		13.4	827	0.0067	0.0123	0.0190	3.86	0.79	Out	172	22	158	106	6	65	-31	-73	1.7



* Thermocouple Locations

** Pressure Drop Indicates Burnout Occurred at this Condition

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NOMENCLATURE

Symbol	Quality	Units
Ae	Effective flow area (geometric area X area coefficient)	cm^2
Ae_s	Swirler effective area	cm^2
A_T	Primary swirler venturi throat area	cm^2
CO	Carbon monoxide pollutant emission	--
CO_2	Carbon dioxide emission	--
D_T	Primary swirler venturi throat diameter	cm
EI	Emission index	g/kg fuel
EPAP	Environmental Protection Agency Emission Parameter	lbs emission/ 1000 lb thrust - hrs
f	Total combustor metered fuel-air ratio	--
f_m	Main stage metered fuel-air ratio	--
f_p	Pilot stage metered fuel-air ratio	--
f_s	Sample fuel-air ratio, determined from gas analysis	--
H	Combustor inlet air humidity	gH_2O/kg dry air
HC	Total unburned hydrocarbon pollutant emission	--
L_T	Length from primary swirler vane exit to venturi throat	cm
M_p	Aircraft flight mach number	--
NO_x	Total oxides of nitrogen pollutant emission	--
P_3 or P_{T3}	Combustor inlet total pressure	atm
$P_{3.9}$ or $P_{T3.9}$	Combustor exit total pressure	atm
T_3	Combustor inlet total temperature	K
$T_{3.9}$	Combustor exit total temperature	K
ΔT_{local}	Local combustor temperature rise ($T_{3.9,local} - T_{3,average}$)	K
$\Delta T_{average}$	Average combustor temperature rise ($T_{3.9,average} - T_{3,average}$)	K
V_R	Combustor reference velocity	m/s
W_3	Compressor discharge airflow rate	kg/s

NOMENCLATURE (Concluded)

Symbol	Quantity	Units
W_c	Combustor airflow rate	kg/s
W_f	Fuel flow rate	kg/hr
W_{f_m}	Main stage fuel flow rate	kg/hr
W_{f_p}	Pilot stage fuel flow rate	kg/hr
W_{f_t}	Total combustor fuel flow rate	kg/hr
η	Combustion efficiency	--

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